THE EVOLUTION OF ELECTRONIC WARFARE EQUIPMENT AND TECHNIQUES IN THE USA, 1901 TO 1945

by

Alfred Walter Price FRHistS

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ABSTRACT

This work describes the evolution of electronic warfare equipment and techniques in the USA, from the first instance of radio jamming in that country in 1901 until the end of World War II in 1945.

It begins with a review of early work on telegraph, radio and radar systems throughout the world, and countermeasures used during trials or in combat prior to World War II. Immediately after the USA entered the conflict in 1941, the Radio Research Laboratory was set up near Boston to develop radio countermeasures equipment for the US armed forces. The organisation rapidly outgrew the capacity of a single laboratory and in October 1942 Division 15 of the National Defense Research Committee was formed, to co-ordinate US work on countermeasures. The activities of RRL and Division 15 are described in detail, using contemporary records and accounts from participants.

Radar jammers developed by Division 15 were first used in action in July 1943 during the invasion of Sicily, and went on to play important roles in support amphibious landings and strategic bombing operations in the European and Pacific theatres of operations. The jamming devices and tactics employed, the enemy attempts to develop counter-countermeasures and the US moves to counter these counters are all described in detail. Conclusions are drawn on the effectiveness of the various types of jamming, based on post-war interrogations of German and Japanese serving officers and technical personnel. Appendices give technical details of the countermeasures devices produced in the USA during World War II, and the development of radar and radar counter-countermeasures in Germany and Japan.

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Alfred Price
Uppingham
Rutland

AUTHOR'S NOTE

In order to maintain the relevance of the account, I have had to stick closely to the usually accepted definition of electronic warfare: that division of the military use of electronics involving actions taken to prevent, reduce or exploit an enemy's use of radiated electro-magnetic energy, and actions taken to ensure one's own effective use of radiated electro-magnetic energy. But to convey a full understanding of this main theme I have had, from time to time, to touch on other subjects on the periphery of electronic warfare. The development of radar in the USA and abroad is covered only as far as is necessary for the reader to follow the main story. The important but separate fields of signals intelligence and crypto-analysis are mentioned only where they influenced the course of electronic warfare. No attempt has been made to cover deception methods not related to electronic warfare.

In each case the ranks and forms of address of individuals are those they held at the time they are mentioned in the text. To assist the modern reader, terms such as MHz, radar, Elint, electronic warfare, etc have been used even though different terminology was in general use during the time period described in the text. German words such as Würzburg, Düppel etc have been anglicised to Wuerzburg, Dueppel etc. For simplicity the AN prefixes for US equipments have been dropped; thus AN/APR-4, AN/APT-2 etc are referred to as APR-4, APT-2 etc.

NOTE ON PREVIOUSLY PUBLISHED WORK ON US ELECTRONIC WARFARE

Prior to this work there had been no concerted attempt to describe and analyse the US electronic warfare effort during World War II and its effect on the enemy. The omission is understandable: by its very nature electronic warfare tends to be shrouded in secrecy, and the technicalities of the subject present further difficulties to researchers trying to gain an understanding of it.

When the first accounts mentioning US electronic warfare appeared soon after the war, the main details of the subject retained security classifications. The 30-page US Government press release Electronics Warfare issued in November 1945 gave a limited, superficial and mainly self-congratulatory insight into a few aspects of the subject. The best account on US electronic warfare published during the early post war years appeared as a chapter in Scientists Against Time by James P. Baxter (Massachusetts Institute of Technology Press, 1948), though even this did little more than scrape the surface of the subject. The multi-volume official histories The Army Air Forces in World War II by W. Craven and J. Crate and History of United States Naval Operations in World War II by Samuel Eliot Morison contained numerous references to the use of radar and radio countermeasures during the conflict.

When the security blanket on US electronic warfare during World War II was finally lifted during the 1960's and 1970's, there was no attempt to produce a detailed analytical work on the subject as a whole though some books touched on aspects of it. Roger Freeman's The Mighty Eighth (1970) contained many references to the use of radar countermeasures during strategic bombing operations by the US Eighth Air Force. Martin Streetly's Confound and Destroy (1977) gave a good account of the operations by the 803rd Bombardment Squadron and other specialist US units involved with radar countermeasures which operated from England in 1944 and 1945, and technical details of some of the countermeasures devices. Fritz Trenkle's Die deutschen Funkmessverfahren bis 1945 (1979) gave an insight into radar developments in Germany during the conflict and attempts to overcome the effects of the US countermeasures. The same author's Die deutschen Funkstoerverfahren (1982) gave details of German attempts to jam Allied electronic systems. Hughston Lowder and Jack Scott's book Batfish (1980) contained an account of the US submarine's operation in which it sank three Japanese submarines on successive nights by homing on their radar transmissions. In 1980 the Association of Old Crows produced a book for limited circulation entitled Radio Countermeasures RCM, which contained parts of the transcripts of interviews of US electronic warfare pioneers carried out by this author. Richard C. Knott's The Black Cats (1981) contained a few references to operations against Japanese radars by US Catalina flight boats during the Pacific campaign. Taken together, these references give only a patchy coverage of the history of US electronic warfare during the period up to 1946; in fairness, it should be said that none of the authors intended more.

CHAPTER 1 BEFORE PEARL HARBOR

Tracing the history of electronic warfare in the United States of America, one can find roots which extend back long before the outbreak of World War II. This chapter will draw together the many different threads of the early part of the story, to establish the degree to which the conceptual and technical groundwork in this field had been established prior to the Japanese attack on Pearl Harbor on 7 December 1941.

The first electronic communications system to go into large scale use was the telegraph, after Samuel Morse invented his apparatus for sending messages over wires in 1837. Six years later the US Congress voted $30,000 for the installation of a line between Washington and Baltimore. Just how poor were military communications, before this invention, is shown by the fact that at this time the principal means of sending messages between the US Navy Pacific Squadron and the Navy Department in Washington was by dispatch vessels sailing around Cape Horn (1); in 1846 the Navy's Pacific Squadron knew nothing of the war with Mexico until an officer who had travelled overland brought the news. (2)

Once the use of the 'speaking wires' was established, they spread rapidly. Undersea cables followed, and in 1858 President Buchanan and Queen Victoria exchanged telegraphed messages of congratulation over the newly laid trans-Atlantic link (3). The more advanced armies and navies readily adopted the device and, since in wartime the denial of an enemy's means of communications was a prize worthy of considerable effort, countermeasures against the new invention would not be long in coming. They were to be used during the first major conflict anywhere in which both sides employed the telegraph on a large scale: the US Civil War.

From the outbreak of the US Civil War in 1861, telegraph lines became an important target for the cavalry raiding forces of both sides. The Union forces, being the more extensively equipped with telegraphic systems, were the more vulnerable in this respect and the Confederate troops exploited this:

> Amongst the rarest breed of men, a kind of Signal Corps elite, were the telegraphers attached to Confederate cavalry commands. These fellows - all of whom also qualified as flagmen - rode at the head of every such command and during many raids into Union territory they switched military traffic to the wrong destinations, they transmitted false orders to the headquarters of Union commanders, they cast suspicion upon all orders that came by wire. And when they had finished the job, they cut all the wire in sight and took home with them as much as they could roll up in a hurry. (4)

Thus were born the techniques of disrupting and spoofing enemy electronic communications, techniques which find considerable relevance today. Because they did not involve 'radiated electromagnetic energy', the telegraph systems and the measures to counter them do not fall within the boundaries defined by the term 'electronic warfare'. Nevertheless, some of the methods were later employed against radiating systems and so deserve mention here.

II

The telegraph revolutionized military communications, but it was not long before science had something even better to offer. In 1888 the German Heinrich Hertz demonstrated that electrical sparks would propagate signals into space at the speed of light. Following this discovery, scientists in several countries pushed the development of the so-called 'Hertzian waves'. And, as in the case with the telegraph, development aimed at military applications soon followed. In 1895 Captain H. Jackson, commanding the Royal Navy torpedo school at Plymouth in England, built a radio system able to transmit morse signals over 100 yards. Two years later the Italian pioneer Guglielmo Marconi demonstrated a system to send and receive signals over a distance of 1¾ miles. (5)
3000 yds.

For overland communications, initially the radio offered merely another way of doing the same as the telegraph was already doing rapidly and efficiently; and it was less effective than the telephone, whose use was spreading rapidly. Oversea communications were another matter, however. Once they were out of sight of land, ships were completely isolated. So those interested in marine communications eagerly grasped the new invention, as a means of solving one of their most intractable problems. Marconi strove to develop a radio set suitable for use at sea and in mid-1897 he achieved a range of 11 miles between the Italian armored cruiser San Martino and the dockyard at La Spezia (6). Also in that year the German pioneer Adolf Slaby forecast that the most important possibilities of the new device would lie in the fields of military and naval communications, and for use with airships. Significantly, he also prophesied the use of radio jamming in wartime. (7)

During Royal Navy manoeuvres off the west of England in 1899, two cruisers and a battleship carried Marconi radio sets and their signals were picked up at distances up to 89 miles. Following this Marconi took some of his equipment to the USA, and in September used it to pass reports to the New York Herald on the progress of the America's Cup yacht races off New Jersey. The US Navy requested a demonstration and Marconi fitted his sets into the battleship USS Massachusetts, the cruiser New York and the torpedo boat Porter. (8)

Now radio at sea began to establish itself as being potentially of equal importance to the telegraph on land. Initially there were very few sets, whose spark transmitters radiated signals over a wide band of frequencies whose mid-point depended on the length of the aerial. As the number of transmitters increased, some with higher powers to give improve range, instances of unintentional jamming occurred as operators tried to pass messages simultaneously. This type of unintentional interference, to both friendly and enemy transmissions, was to become a normal feature of military communications in the years to follow and even in the 1980's the problem remains.

The first recorded instance of deliberate radio jamming took place in September 1901, in the USA. Interestingly, it was aimed at securing commercial gain rather than military advantage. As now, there was considerable public interest in the America's Cup yacht races; and the newspaper first to reach the stands carrying each result stood to reap a large profit. In that year Marconi obtained a contract from the Associated Press to send radio reports on the America's Cup yacht races. Another concern, the newly formed Wireless Telegraph Company of America, secured a similar contract to pass reports to the Publishers' Press Association. A third company, the American Wireless Telephone and Telegraph Co, failed to get a sponsor but decided to exploit the situation in a manner hardly in keeping with the highest standards of business ethics. The AWT&T used a transmitter more powerful than its competitors and one of its engineers, John Pickard, worked out a method which allowed him to jam signals from the other companies while at the same time reporting on the progress of the race from his boat. He evolved a simple code whereby one 10-second dash, repeated at intervals, indicated that the US yacht Columbia was in the lead, two such dashes indicated that the British yacht Shamrock was ahead, three that they were neck and neck, and so on. Thus only the AWT&T was able to pass accurate reports on the races, and profited accordingly. Pickard's gloating account of the incident stated:

> When the yachts crossed the finish line we held down the key and then continued to hold it down, by the simple method of putting a weight on it. Thus radiating waves . . . we sailed for our home port, and the batteries lasted for the entire hour and a quarter that we utilized to send the longest dash ever sent by wireless. (9)

In December 1901 Marconi sent the morse letter 'S', three dots, over the 2,000 miles from Newfoundland to Cornwall in England using a 10 Kw transmitter radiating on a center frequency of 310 KHz. It was a dramatically impressive demonstration, which proved beyond doubt that radio was the way ahead for long range communications for ships at sea and between points not connected by cable. (10)

The first intentional use of radio jamming by the military occurred in 1902, during Royal Navy fleet exercises in the Mediterranean. During these the 'enemy' fleet was blockaded in harbour, watched by cruisers who were to summon the main battlefleet by radio if there was any attempt at a breakout. When the 'blockaded' ships put to sea the cruisers tried to report this, but their signals were jammed by simultaneous transmissions from the 'enemy' and the main battlefleet failed to engage. (11)

By the time of the US Navy fleet manoeuvres in the summer of 1903, that service possessed five radio stations along the Atlantic coast and had five ships equipped with the device. For the exercises the force was divided into two. 'White', the enemy fleet, was to start 500 miles east of Cape Cod and attempt a simulated landing of troops on the New England coast. The 'Blue' fleet was to try to engage the 'white' force before it reached the coast and had four of the ships fitted with radio, positioned as a screen to warn of the 'White' approach. Only one of the 'White' ships carried radio, the USS Texas; she was to try to jam the sighting reports and so prevent the 'Blue' forces closing in. That was the plan, but it failed to work and the radio man on board Texas ended up in the brig. Afterwards the unfortunate man explained:

> I was on watch and everything was working fine. I heard a message begin, and the first three letters were G, O and L, so I knew it was going to be GOLD and that it was from the other side. I reached for the key, but the Flag Lieutenant who was with me said, "No, don't do that, I want the entire message." When the message was ended, the Lieutenant said "Make interference" and I said "Sir, it's no use now. The message has gone out with a speed of 186,000 miles a second and we can't catch up with it." So here I am on bread and water. (12)

It is the first recorded instance of a conflict between those who wished to listen to enemy radio signals for intelligence, and those who wished to jam them to prevent the information reaching the enemy. The problem persists to the present day.

By 1903 the jamming of enemy radio communications was 'an idea whose time had come'. This was born out the following year soon after the outbreak of the Russo-Japanese war, the first in which both sides' naval forces used radio. On the morning of 14 April 1904 the Japanese armored cruisers Kasuga and Nisshin bombarded the Russian naval base at Port Arthur, using radio to spot the fall of shot and pass corrections. At the radio station on shore one of the Russian operators heard the Japanese signals, realized their importance and used his spark transmitter to jam them. As a result the bombardment caused little damage and few casualties. Radio jamming had made its first, unplanned and improvised, step into the arena of combat. (13)

During the remainder of the conflict, which reached its climax with the resounding Japanese naval victory in the Tsushima Strait in May 1905, the Japanese made considerably more effective use of radio than their opponents. The Russian Navy preferred to conceal the presence of its ships wherever possible by maintaining radio silence, to listen to and exploit enemy transmissions when it could and, on rare occasions, to jam them. (14)

In 1906 the US Navy fitted a primitive radio direction finder to the collier Lebanon for tests. Although this early equipment demonstrated only a limited capability, the Chief of the USN Bureau of Equipment saw its possibilities and wrote informing the Secretary of the Navy that

> The results thereon obtained indicate that a development of the system will have a far-reaching effect on the safety of vessels at sea, and will possibly play an important part in naval warfare by making it feasible to locate the direction of an enemy's fleet. (15)

From the opening of World War I, in August 1914, there was widespread use of radio jamming. This began on 4 August, the day before Britain entered the war on the side of Belgium and France against Germany and Austria. In the Mediterranean the British cruisers Indomitable and Indefatigable passed close to the German cruisers Goeben and Breslau; both forces were moving at high speed, neither knowing whether the other was likely to open fire. In the event there were no shots but, as the German Admiral Souchon later wrote: 'The British cruisers merely attempted to jam systematically our wireless communications.' (16)

During subsequent naval actions communications jamming was employed from time to time, though the increasing success of crypto-analysis put a brake on this activity as the war progressed: the intelligence value from de-crypted enemy signals was often far greater than the transitory advantage to be gained from jamming them. Naval forces also became conscious that too liberal a use of radio could betray a great deal of useful information to the enemy, even if cyphers remained secure. Commanders stressed the importance of maintaining radio silence whenever possible, and of minimizing signals traffic when it was not. For close manoeuvring, fleets reverted to the older visual signalling methods. Once warships were within sight of the enemy, however, captains were permitted the free use of radio.

Early in 1915 the Royal Navy erected a chain of direction-finding stations along the east coast of England, whose bearings could establish the position of any ship or aircraft using radio in the North Sea area. The stations employed the well-known Bellini-Tosi system of direction-finding aerials, but their performance was greatly enhanced by a sensitive new type of amplifier developed by the Marconi company and using thermionic valves. This chain of stations proved particularly useful in providing information on the movements of Zeppelins during operations, as their crews would frequently request navigational bearings from direction-finding stations in Germany. (17)

When the USA entered the conflict in April 1917 its naval battle squadron under Admiral Rodman joined the British Grand Fleet and used British signals equipment and procedures. US Navy destroyers and escorts operated separately, however, and retained their voice radios which were a great advance on the sets fitted to the Royal Navy ships. Also some US destroyers carried the Type 995 radio direction-finder, which proved of considerable value for assembling hunting groups and convoys and also for taking bearings on U-boat transmissions. (18)

Radio for air-to-ground communications assumed considerable importance during World War I, usually to pass tactical reconnaissance reports or gunfire corrections. Because these were usually of little intelligence value to the enemy, they were often jammed. Operators trying to take down gunfire corrections from artillery observation aircraft found unintentional interference from nearby friendly machines at least as much a problem as the deliberate jamming from the enemy, however. The official British history described one method of lessening such interference, used during the Battle of the Somme in 1916:

> One great difficulty was the ease with which wireless messages from spotting airplanes were jammed by similar messages simultaneously emitted by friendly adjacent aircraft. A remedy was found by the adoption of the "clapper-break", by which the pitch or tone of the note sent out by the aeroplane would be varied. This simple device made it possible to double the number of aircraft used for spotting in any given area, and at the time the battle opened wireless aeroplanes, in the proportion of one to every 2,000 yards of trench-line, could operate

> with the artillery without the risk of finding their signals jammed. (19)

The clapper-break was also successful in reducing the effect of deliberate jamming, and can be considered the first example of an electronic counter-countermeasure. Information is sparse on the use of radio jamming by or against US forces during the conflict. Since the US Army and Air Service made considerable use of British signals equipment, however, it is likely that their experiences were similar to those of the British forces.

Following the end of World War I, the US Naval Research Laboratory at Anacostia conducted experiments to improve high frequency communications between ground stations and ships at sea and aircraft airborne, with initial forays into the fields of radio teleprinters, photo facsimile transmission equipment and television. In 1929 the NRL devoted some effort to 'avoiding enemy detection, and detecting enemy transmissions' as well as the 'creation of interference for the enemy'. NRL engineers modified existing communications transmitters to sweep across a band of frequencies, to cause interference to enemy systems. They considered that if such jamming was required in time of war, in-service communications transmitters with relatively simple modifications would be sufficient to provide it. (20)

During the 1920's and 1930's several nations experimented with radio controlled aircraft and 'flying bombs'. The NRL conducted experiments in this field, then went on to consider what countermeasures would be necessary should the US Navy find itself confronted by such weapons. The first requirement was a receiver to detect the frequency used for the enemy control signals. To prove the feasibility of such a system NRL engineers modified a Model SE 2952 receiver to sweep continuously through the band between 240 and 650 KHz. When it picked up the signals a neon tube was arranged to strike up behind the appropriate point on the frequency dial. This was probably the first continuously scanning visual display intercept receiver ever built. (21)

III

By the early 1930's transmitters were becoming sufficiently powerful, receivers sufficiently sensitive and aerials sufficiently directional to permit an entirely new development in the field of electronics: the device we now call radar.

During his experiments in the 1880's Heinrich Hertz had demonstrated that metal plates would reflect electromagnetic waves, and the concept of detecting distant objects by such means can be traced back to his initial experiments. The first formal mention of such a system appears to have stemmed from the pen of the US inventor Nikola Tesla, famous for his innovative work in the development of alternating current electrical systems. In an article entitled The Problem of Increasing Human Energy published in June 1900, he wrote:

> When we raise the voice and hear an echo in reply, we know that the sound of the voice must have reached a distant wall, or

> boundary, and must have been reflected from the same. Exactly as the sound, so an electrical wave is reflected, and the same evidence which is afforded by an echo is afforded by an electrical phenomenon known as a "stationary wave" - that is, a wave with fixed nodal and ventral regions . . .
> Stationary waves in the earth will mean something more than mere telegraphy without wires to any distance. They will enable us to attain many important specific results, impossible otherwise. For instance, by their use we may produce at will, from a sending station, an electrical effect in any particular region of the globe; we may determine the relative position or course of a moving object, such as a vessel at sea, the distance travelled by same, or its speed. (23)

Tesla's concept was visionary rather than practical, and it has only loose ties with radar as we now know it. Within a short time, however, more practical experiments would begin along these lines.

In 1904 the German scientist Christian Hulsmeyer patented a device with a transmitter and a receiver mounted side-by-side and so arranged 'that waves projected from the transmitter can only actuate the receiver by being reflected from some metallic body, which at sea would presumably be another ship'; in theory the device would also detect iceburgs. Hulsmeyer called his invention the 'Telemobiloscope'; the echo signals were to sound a bell, to warn of the proximity of other ships or objects. The apparatus employed a spark transmitter and coherer receiver.

In May 1904 the inventor reportedly gave a successful demonstration of his device at the Hohenzollern Bridge at Cologne, using ships passing up and down the Rhine as targets. As they approached his apparatus the bell would ring, and it ceased when the ship passed outside the beam of the apparatus. Hulzmeyer went on to extend the range of his detector to 3,000 metres, but although it aroused some interest there were no buyers (24). Given the lack of effective directional aerials and sensitive receivers in 1904, it would seem likely that the device had a high false alarm rate which would have mitigated against its usefulness.

Several nations claim the invention of radar for their own. As we have observed, however, by the 1930's all the necessary developments in transmitter, receiver and aerial design had been made and it remained only to assemble such a detection system. Radar was now a device 'whose time had come', as is borne out by the fact that scientists working independently in the USA, Great Britain, France, Germany, Holland, Japan and the Soviet Union all produced working sets.

In the USA the NRL began experiments with radio detection as early as 1922, using a continuous wave transmitter on 60 MHz set up at Anacostia; it radiated across the Potomac and Anacostia rivers, to a receiver at Haines Point. As ships passed through the transmission path they caused fluctuations in the strength of the received signals (25). The device had an effective range of about 3 miles. This was an 'interference detector' rather than a 'radar', but its importance to the story is that it marked a step in the development of the latter device. This same principle would be resurrected in the modern times, for use in forward-scatter over-the-horizon radar systems.

Development of the interference detector at the NRL continued, and by 1934 the device was able to detect aircraft at 50 miles. Members of the Subcommittee on Naval Appropriations of the House of Representatives watched a demonstration of the device, which impressed them sufficiently to gain a special appropriation of $100,000 to further work in this field. At the beginning of 1935 NRL engineers began testing a 60 MHz pulsed radar to detect aircraft. Initially there were severe problems with this, however: pulses from the high powered transmitter caused 'ringing' in the receiver, which swamped the echo signals returned from objects nearby. (26)

Meanwhile, unknown to the researchers in the USA, work of a similar nature was moving ahead fast in Great Britain and Germany. By June 1935 a British experimental pulsed radar operating on 11 MHz was giving detection ranges of 17 miles on aircraft; in March 1936 an improved version was able to detect aircraft 75 miles away (27). And by September 1936 a German radar, operating on what was then the extremely high frequency of 600 MHz, detected an aircraft 12 miles away. (28)

With the threat of impending war still remote from the USA, the development of radar lacked the urgency of that in Europe. Nevertheless, US developments did not lag far behind those elsewhere. By April 1936 NRL engineers had built a 28 MHz pulsed radar which gave 10 mile detection ranges on aircraft; by the following June its range was 25 miles. By November 1936 a new type of radar, operating on 80 MHz, was detecting aircraft 38 miles away. In April 1937 an experimental 200 MHz radar fitted to the destroyer USS Leary detected aircraft at 20 miles; by the following year a more advanced ship-borne set gave double this range. In December 1938 a 200 MHz XAF radar went to sea on the battleship USS New York, and early in 1939 it was used during the fleet exercises in the Caribbean. It detected aircraft at 100 miles (equivalent to more than half an hour's warning of attack, given the speeds of bombers at that time), and ships at 15 miles. The XAF radar proved so successful that the Model CXAM patterned on it went into production, and would enter service in the spring of 1940. (29)

The NRL passed details of its work on radar to the US Army Signal Corps laboratory at Fort Monmouth, and by the end of 1936 the Army had tested a pulsed radar operating on 110 MHz. In May 1937 the Secretary for War, the Army Chief of Staff and the Chief of the Air Corps observed a successful demonstration of a combined radar and infra-red detection system linked to a searchlight. The infra-red system was later discarded but the radar, modified to operate on 200 MHz, became the SCR-268 coastal and anti-aircraft gun control set; this was the first radar to go into production for the US Army and it would enter service early in 1941. (30)

Although the evolution of radar in the USA is not, strictly speaking, part of the story of electronic warfare, the reader needs an insight into this subject because the development of counter-measures would follow hard on the heels of that of radar. By the outbreak of World War II in Europe, in September 1939, work in the USA on radar was well advanced and the nation had established a pool of scientists, physicists and engineers who understood the necessary techniques. Also, within the military, there were a few forward-looking officers who perceived the importance of such equipment in any future conflict and who ensured the necessary resources were made available for its development. Thus, unwittingly, firm foundations were being laid for the US entry into the field of electronic warfare when this became necessary.

IV

Once radar was established as an important means of detecting and locating enemy ships and aircraft, it could be only a matter of time before somebody thought of jamming it. As early as October 1935 Robert Watson-Watt, in charge of the British programme to develop radar, had received a government request 'To consider whether radio location could be defeated by deliberate jamming'. Following this, one of Watson-Watt's departments at the research establishment at Bawdsey in Suffolk began theoretical work on the problem. In January 1938 the team began jamming tests, using a ground spark transmitter against the radar at Bawdsey and two others along the coast. In May 1938 the first airborne jamming test took place, using an interrupted-continuous-wave transmitter on board a London twin-engined biplane flying boat. (31)

Following these tests, various anti-jamming systems were built into the Chain Home radars being erected along the east coast of England - the first-ever examples of what we now call radar electronic counter-countermeasures (ECCM). Stations were able to transmit and receive on four different frequencies in the 20 to 52 MHz band, so that operators could select the frequency least affected by enemy jamming. The radar was fitted with an intermediate frequency rejector unit with a loudspeaker, so the operator could listen to the intensity of the jamming; he then altered the tuning or the bandwidth of the receiver's intermediate frequency amplifier, to reduce the sound from the loudspeaker and also the effect of the jamming. The operator could vary the pulse repetition frequency of the radar, to counter pulse-locked jamming. Another interesting idea was the use of variable colour afterglow on the A-scope cathode ray tube: the instantaneous trace appeared in blue, the afterglow in yellow. By viewing the screen through blue, green or yellow filters, the operator could see through some types of jamming (32). Then, as now, the ability to detect aircraft through jamming depended to a great extent on the degree of training, skill and experience of individual operators.

The general conclusion formed after the British jamming tests in 1938 and 1939 was that, with the help of the various anti-jamming systems, a good operator with some training should be able to track aircraft through any jamming likely to be met under operational conditions. After conversations with some of those on the periphery, however, the author has formed the impression that the tests were run with the intention of producing only this conclusion. In other words, the jamming was not allowed to exceed the ability of the radars to operate through it. To the reader in the 1980's such an attitude might seem short-sighted. But it should be remembered that in the late 1930's radar was like a prematurely born infant, having to fight hard for the resources on which would depend its survival and development. Too effective a demonstration of the means by which an enemy might neutralize the device, early on, might have given the financiers an excuse to cease funding the project altogether. There was another consideration. In Britain at this time, as in other countries working on radar, very few people knew about the device. So the only people in a position to develop jamming systems were those same engineers who had worked so hard to make the device work in the first place. It would have been asking too much of human beings, to expect these engineers to put their hearts into defeating what they had created.

Thus, for understandable bureaucratic and human reasons, the idea of radar jamming was not pushed as hard as it might have been in Great Britain in 1938 and 1939. Looking at US radar development during this period, one can detect signs that similar influences were probably at work here also. Certainly there was no serious attempt to test any form of jamming against the early US radars.

For the first 8 months after the outbreak of the war in Europe, the combatants warily sized each other up. Then, in May 1940, the Germans struck in the west and, after a victorious campaign lasting just over a month, they forced Holland, Belgium and France to capitulate. Only Great Britain remained in the conflict against Germany. Her first line of defence was the squadrons of Royal Air Force Fighter Command, and their success depended on the chain of radar stations along the south and east coasts of England. The Battle of Britain opened in July and after some initial skirmishing the Luftwaffe sent dive-bombers to attack the radars - the first-ever example of what are now termed defence suppression 'hard-kill' countermeasures. The British radars were well emplaced, however, and the small bombs carried by the dive bombers could not knock out the sets for more than a few hours at a time. Moreover, the defending Spitfires and Hurricanes inflicted heavy losses and the attackers were forced to abandon this countermeasure. Then the German Luftwaffe tried another tack. In September its signals personnel erected a ground radar jamming station at Mount Couple, a hill overlooking Calais. The type of jammer employed, code-named 'Breslau', radiated 1 Kw of noise on spot frequencies in 22 to 50 MHz band used by the Chain Home radars on the other side of the Channel (33). Due to its fixed position, however, the Mount Couple station was never able to prevent at least some of the British radars plotting the incoming German attack formations at any given time. Also, the anti-jamming devices built into the Chain Home radars assisted the more experienced operators to work through all but the worst of the jamming.

V

Meanwhile, unknown to its makers, a US-built radio receiver was starting to play an important part in a different electronic battle now developing in Europe. During the late spring of 1940 the British Air Ministry Scientific Intelligence Directorate, headed by a young physicist named Dr R.V. Jones, began to receive disquieting reports from several sources on a new and obviously very secret German device code-named 'Knickebein'. In fact Knickebein ('crooked leg') was a long range blind bombing system similar to the radio range navigation system then in common use, though initially Jones did not know this. A ground transmitter radiated a beam to mark a flight path for aircraft, with morse dots to one side of the beam and morse dashes on the other; in the center lane the dots and dashes merged to give a steady note. To fly the beam, pilots had only to stay in the zone where they heard the steady note signal. The German Knickebein system worked on frequencies in the 30 to 33.3 MHz band and, in preparation for the planned night bombing onslaught on Britain, several new transmitters were erected in France and Holland following the capture of these countries. Although Dr Jones had evidence that the German system used transmissions on frequencies around 30 MHz, at that time the Royal Air Force had no signals intercept organization equipped to examine that part of the spectrum (34). In its quest for a suitable intercept receiver, the British Air Ministry bought several examples of a receiver intended for 'ham' radio enthusiasts and covering the band 27 and 143 MHz: the S.27 made by the Hallicrafters Corporation, a small company located just outside Chicago (the Hallicrafters Corporation would later become a major producer of electronic warfare equipment and today, as part of the Northrop Corporation, is still active in this field). One S.27 was fitted into an Anson twin-engined reconnaissance aircraft, for what became the first British airborne Elint missions (35). On its third flight during the hunt for the mystery German signals, on 21 June 1940, the crew of the Anson found what they were looking for: a full pattern of Knickebein signals aligned over Lincolnshire with morse dots to the south, dashes to the north and a steady note signal running up the middle. Once the pattern of the signals was known, the method of operation of Knickebein was immediately obvious. The well-known 'Battle of the Beams', the Royal Air Force campaign to jam Knickebein, stemmed directly from this all-important Elint mission. (36)

Early in 1941 the Hallicrafters S.27 was again used by the British to considerable effect, this time to plot the positions of the 125 MHz German Freya early warning radars on the other side of the English Channel. Derrick Garrard, a member of Dr R.V Jones's staff, described to the author his 'do it yourself' work in this field:

> I took my car to various points on the south and east coasts of England. On the back seat I had the Hallicrafters receiver, running off a separate large 6 volt battery so that it would not drain the car's battery; between stops to search for enemy signals, I would re-charge this additional battery from my engine-driven generator. The car had a sun roof which I would

> open, and poke out my home-made H aerial. That was in the days before the term "anaprop" [anomalous propagation] existed, but we knew that this infrequent but fairly predictable form of propagation existed. Because of this I was able to pick up the Freya signals and get rough bearings on them from up to 130 miles. As the German beam swung round it would illuminate the horizon - the effect we now call "forward scatter". This must have been one of the very first observations of this effect.

Having established the approximate positions of several German radars on the other side of the Channel, Garrard returned with a Royal Air Force VHF fixer van, normally used to track friendly fighters from their radio transmissions, and with this was able to refine his bearings. He observed the signals from each radar for as long as 30 minutes, taking repeated bearings and then averaging his results. With this system he triangulated the positions of several Freyas along the coast between Holland and the north coast of Brittany. Later, when the accuracy of plotting would be confirmed photographically by reconnaissance aircraft, Garrard's methods were shown to be surprisingly accurate - within half a degree in many cases. (37)

VI

Initially the war in Europe had little effect on radar development in the USA. But following the rapid German victories over France, Holland and Belgium in the summer of 1940, and the hasty evacuation of the British forces from the mainland of Europe, the possibility of the USA becoming embroiled in the conflict increased greatly. Winston Churchill was anxious to ensure that US scientists received the full benefit of his nation's work in this field, so that the fight could continue even if the Germans invaded Britain. In

September 1940, when the Battle of Britain was at its height, he sent Sir Henry Tizard to the USA at the head of a technical mission. At first their American counterparts treated the visitors with reserve. But then Tizard produced his ace of trumps: the high-power magnetron, developed by Dr. J. Randall and Mr H. Boot at Birmingham University a few months earlier, which produced an unprecedented 10Kw at a frequency of 3,000 MHz: sufficient to power a radar operating on microwave frequencies. The revelation marked the opening of a lengthy period of technical co-operation between the USA and Great Britain in radar and, later, countermeasures. The US Radiation Laboratory, formed a few weeks earlier at the Massachusetts Institute of Technology under Lee DuBridge to further the development of radar in the USA, eagerly grasped the new invention and set about the development of new types of radar to exploit its potential to the full. (38)

Part of the remit of the Radiation Laboratory was to investigate methods of countering enemy radars, and Dr Luis Alvarez and his section began work in this field. At this time the US possessed virtually no information on radar developments by her main potential enemies, Germany and Japan. Alvarez appreciated that without such intelligence no jamming could take place, so his first move was to initiate the development of an airborne receiver to cover the frequency band 100 and 950 MHz (almost certainly the British use of the Hallicrafters S.27 receiver for Elint work was not known to the US authorities at that time). (39)

At about this time the Dr Don Sinclair, a Canadian working with the General Radio Company at Cambridge, Massachusetts, began work on the receiver portion of a field strength measuring set intended to cover the band 100 to 3,000 MHz. To achieve the required broad tuning range, the receiver used the novel 'butterfly' tuning device which Sinclair himself had invented. It soon became clear that the unusual receiver might be suitable for a role quite different from that for which it had originally been intended, however, and in July 1941 the Radiation Laboratory placed an order with General Radio for prototypes of an intercept equipment based on Sinclair's receiver. The device, which received the General Radio prototype designation P-540, was to become the first purpose-built US radar intercept receiver. During tests the P-540 continued to show promise and the Army Signal Corps placed an order for a hundred receivers of this type, now designated the SCR-587, with the Philco Corporation. (40)

At this time several of those at the Radiation Laboratory treated the idea of their own radars being jammed almost like a dirty word, something not to be mentioned in polite conversation. Win Salisbury recounted an incident when the Radlab's new centimetric radar ran into difficulties during bench testing:

> One day Lee DuBridge had Ed McMillan and me into his office and said "We've got a problem here. Every day at 4 o'clock, the new radar stops working. I'm appointing you two to find out why." So Ed and I started investigating and we put an oscilloscope on the output of the IF amplifier to see what sort of modulation was there. On the screen it looked exactly like a

> speech waveform. So we fitted a detector and loudspeaker and found it was an MIT radio ham coming in with his radio telephone, on the IF frequency promptly at 4 o'clock each day.
> We had a big meeting about this, and when I said what had happened up went the cry "Kill the ham!". In the end I stood up and said "Gentlemen we should not kill this ham, we should give him a vote of thanks. How long do you think our radar will survive in service, if this sort of thing will interfere with it?" (41)

Reluctantly, those present agreed to allow the 'ham' to continue operating, and work began on improving the shielding around the intermediate frequency amplifier of the new radar.

Meanwhile, the Naval Research Laboratory at Anacostia was pushing ahead with the development of another aspect of electronic warfare: the high frequency direction finder, to pin-point hostile radio transmitters operating in the band 3 to 30 MHz used for long range communications. Back in 1936 the NRL had developed the DT ground direction finder which performed effectively in this role; by 1940 several were in service. Now the need was for a similar high frequency direction finder (HFDF) suitable for carriage on warships, to enable them to home on enemy transmissions (the direction finders fitted to US warships in World War I operated only on medium frequencies, below 3 MHz). At sea, the DT equipment was not a success: due to reflections from the ship's structure, the bearings it provided were so unreliable that they were of no operational use. (42)

The breakthrough came after the fall of France, when Maurice Deloraine and three compatriots who had been working on a new type of high frequency direction finder for the French Navy escaped to the USA with plans of the new device. Working at the Federal Telecommunications Laboratory at Amagansett, Long Island, the Frenchmen soon had running the prototype of a shore-based direction-finder to their design; they went on to build a ship-borne version, which would later enter service with the US Navy as the DAQ. (43)

VII

At the beginning of December 1941, immediately before the USA entered the war, the development and production of radar for the nation's armed forces was well advanced. By that time the US Army had in service a few SCR-268's, a 200 MHz set for coastal and anti-aircraft gun control being produced by the Signal Corps Laboratories and by Western Electric. For early warning on 100 MHz there was the SCR-270, and its transportable version the SCR-271, both in production at Westinghouse (44). The US Navy had twenty CXAM's, a 200 MHz surface and air search radar made by RCA, fitted into battleships, aircraft carriers and cruisers. That service had also received the British ASV (air to surface vessel) Mark II radar, an airborne set which operated on 176 MHz; with some changes, this was about to enter mass production as the ASE (US Army designation SCR-521) for fitting to the PBY Catalina and other patrol aircraft. A more advanced US-designed radar for the same purpose, the ASB operating on 515 MHz, was in the initial test stage and would later be mass produced by RCA, Bendix and Westinghouse Electric. For its night fighters, the Army Air Force had acquired a few British AI (Airborne Interception) Mark IV radars operating on 200 MHz; this set was about to go into production at Bell Telephones as the SCR-540. Two NRL-designed equipments were on the point of entering service with the US Navy: the 114 MHz SD radar for submarines produced by RCA; and the 700 MHz FA and FC sets for shipborne gunnery control both made by Western Electric(6). And at the Radiation Laboratory prototypes were running of airborne and ground radars operating on 3,000 MHz, powered by magnetrons. (45)

Thus on 7 December 1941, when Japanese aircraft attacked Pearl Harbor, the US armed forces were using many different types of radar though in small numbers. Qualitatively, the sets entering production in the US were equal to those being built in other nations; and some of the microwave fire control and airborne intercept radars being prepared at the MIT Radiation Laboratory for production would become the best in the world in their respective categories. Moreover the nation's huge electronics industry, the largest in the world, was becoming more and more committed to the production of radar.

Apart from the work on the P-540 intercept receiver (later designated the SCR-587) which the MIT Radiation Laboratory had commissioned, and the high frequency direction finders for the US Navy, little of the work taking place in the USA at this time can be considered to fall totally within the boundaries of electronic warfare as defined at the beginning of this work. For a concerted and systematic entry of the USA into this field three things were necessary: first, the nation had to have the 'background technology' in electronics necessary to develop such equipment; secondly, it needed sufficient spare manufacturing capacity to bring such a program to fruition; and thirdly, the need for electronic warfare systems had to be perceived by those in positions of authority able to switch money and resources to develop such equipment. On 7 December 1941 the USA obviously possessed the first two of these requirements in full measure. The third requirement was not yet satisfied, but it would be in a remarkably short space of time.

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CHAPTER 2 PLUNGE INTO THE UNKNOWN

The first moves to form an organization in the USA devoted solely to the development of radio countermeasures came from the Navy on 11 December 1941, just four days after the Japanese attack on Pearl Harbor. On that day Admiral Julius Furer, one of the co-ordinators of naval research and development, convened a preliminary meeting to discuss setting up such an organization. Representatives of the US Government Office of Scientific Research and Development (OSRD), the Navy and the Radiation Laboratory were present. This meeting led to a formal conference between the OSRD and the Navy on 22 December; amongst those who attended were Admiral Furer, Rear Admiral Alexander Van Keuren (Assistant Chief of the Bureau of Ships) and Dr Karl Compton (President of the MIT). Following this, a letter was sent to the National Defense Research Committee (NDRC) requesting that it consider forming an organization to development countermeasures equipment. The recommendation was accepted. (1)

The next step was to select someone of standing within the US scientific community to head the enterprise. The obvious initial choice for the post was Dr Luis Alvarez, whose section at the Radiation Laboratory had initiated work on the P-540 intercept receiver at the General Radio Company. Alvarez was heavily involved with the development of microwave radar at the time, however, and declined the offer. But he strongly recommended for the position Dr Frederick Terman, then head of the Department of Electrical Engineering at Stanford University in California (2).

Terman was author of 'Radio Engineering', a much-used textbook on electronics at that time, and was ending his year in office as president of the Institute of Radio Engineers (now incorporated in the the IEEE.)

On 28 December Terman received a telephone call from Dr Lee DuBridge, the Director of the Radiation Laboratory , asking him to call as soon as possible to discuss an important matter. Terman, in New York for a meeting at the IRE, called on DuBridge who asked him if he was willing to set up a civilian organization to develop radio and radar countermeasures equipment for the US armed forces. Terman did not give an immediate answer; as he later told the author:

> I spent several days considering DuBridge's offer, wondering what I might be letting myself in for if I accepted. I really had no idea of what would be involved. But in the end I came to the conclusion that if I was going to get involved in the war effort, this new organization was more important that anything else I was likely to become involved in. Accordingly, before leaving Boston several days after it was tendered, I accepted DuBridge's offer. (3)

Following this acceptance, the NDRC drew up a formal proposal for the establishment of the radio countermeasures laboratory under Terman, and allocated the sum of $300,000 for the first six months' operations. The text of the letter of proposal is given in full as Appendix A. Now the way was clear for the laboratory to open and start recruiting staff. Terman continued:

> On 12 February 1942 I took up my post at Cambridge. At the start I had to work with Wheeler Loomis, DuBridge's No 2 man, to set up my operation which would work in parallel with his. Loomis was a tough, hard-boiled character. It used to be said that at the Radiation laboratory there was a division of

> labor: Lee DuBridge to say "yes" to everyone, and Wheeler Loomis,as to say "No!" Everybody loved Lee DuBridge, they almost hated - but greatly respected - Loomis. Soon after I started I asked Loomis "What do you think is needed in the way of countermeasures? Where should I turn for the best advice?" He looked me straight in the eye and replied "We don't know. That's what we hired you for!" Looking back, it was the best charter I could possibly have been given. Nobody in the US knew anything about radio countermeasures, it was my job to find out what could and should be done. (4)

On 16 February Karl Compton wrote a formal letter to Dr Terman on behalf of the NDRC, to confirm the latter's appointment as head of the new radio countermeasures organization (the text of the letter is given in full in Appendix B):

> It is understood that the R.C.M. project initially will be set up as part of the Radiation Laboratory and will operate for the present as a separate and distinct project under the general policies and within the structure of the Radiation Laboratory. For various reasons, however, it is desirable that this project become administratively separate from the Radiation Laboratory as soon as possible, after which time the R.C.M. project and the Radiation Laboratory will be parallel activities, each under a director, both reporting to Section D-1.

The letter went on to stress that it would be up to Terman and his new team to decide which avenues they should explore:

> It is impossible at the present time to outline the scope and size of the R.C.M. project. The Microwave Committee has agreed, at the request of the Army and Navy, to undertake an intensive program on this subject. The particular lines of attack to be undertaken, however, will have to be outlined by your own organization, in consultation with the armed services, Microwave Committee and Radiation Laboratory members. (6)

From the beginning it was made clear to Terman that although for the time being his section would come under the administrative control of the Radiation Laboratory, the work of the two groups was to be kept apart. Only a small proportion of those working at the Radlab would be allowed access to the RRL; most of those working on countermeasures were allowed to visit the Radlab, however, to acquaint them with the latest work on radar. The reason this one-way passage of information was that those working on countermeasures would need access to intelligence information on enemy equipment, not necessary to those working on radar. To provide radar expertise for Dr Terman's new group two Radiation Laboratory engineers were transferred to it, Dr Win Salisbury and Dr Richard Raymond. At the same time Dr Don Sinclair, working at General Radio's Cambridge laboratory on the P-540 receiver, began to split his time between that laboratory and RRL. The fact that Sinclair was a Canadian citizen made little difference: he held the necessary security clearances and was obviously the best man to take charge of the work on intercept receivers at RRL. (7)

Dr Terman established his organization in Building 24 of the Radiation Laboratory, on the MIT Campus at Cambridge. Soon afterwards it received the title 'Radio Research Laboratory', a name intended to conceal its true function. Terman had no difficulty getting all the money he could reasonably spend, his main problem was finding electronics engineers of the necessary high quality for his laboratory (he regarded countermeasures as essentially an engineering task, not requiring any of the basic research occupying the scientists and physicists working on radar). At the beginning of 1942 the US economy was gearing itself for war and many organizations - including the armed forces - were also looking for people with expertise in this field. Terman was not permitted to poach engineers from any organization involved in the war effort, but those working outside it were fair game; he described some of the unconventional methods he used to get recruits:

> John Byrne, who became my chief engineer, I picked up almost by accident. On my way back from the east after being offered the job, we happened to be flying on the same plane out of Chicago. He had been head of electronic engineering at Ohio State University. He had written several papers and I had heard of him, though at that time I did not know him very well. Anyway, we sat next to each other on the plane and it turned out that he was in the process of changing jobs. He was about to go and work for Collins Radio but as yet he was not involved in the war effort, so I asked if he would like to join my group. He said he would, and joined me soon after the start. (8)

Soon afterwards Harold Elliott, a mechanical engineer and old friend of Terman's, joined the group; widely known and respected, he held several patents including one for a push-button tuning system for car radios which gained him considerable sums in royalties. By the end of February 1942 the staff of the Radio Research Laboratory comprised Terman, Byrne, Elliott, Salisbury and Raymond, three technicians and a secretary. Now the expansion of the team began to accelerate. Terman continued:

> Still more people were needed, many more. Gradually we evolved an effective system of finding the right ones. I contacted several of those who had been students of mine at Stanford, including several who were then teaching electronics at other schools, and hired them. As each newcomer was taken on, he was asked if he knew anyone he could recommend for our project. And when those new ones joined us, they were given the same treatment. (9)

During March 1942 the staff at the RRL increased to eighteen and the group took over the second floor of the Hood Building at Cambridge. Terman was getting capable engineers to join him, but still he had no clear idea of the direction in which he ought to be directing their efforts:

> Now that I had necessary clearances, it was easy for me to get in touch with the radar experts at the Radiation Laboratory. And they were very keen to talk about their latest ideas. But there simply was nobody we could turn to in the US when it came to planning countermeasures. In our group we did a lot of talking, but we really did not know whether one needed .5 watts, 5 watts or 500 watts to jam a radar. Nor did we have much information on the enemy equipment. We knew the Germans had radar, but we had few details; we had no idea at all as to whether the Japanese had even heard of radar. (10)

Terman was keen to let his young engineers have free rein as far as possible to develop their own ideas and schemes. Having just come from the Radiation Laboratory, Richard Raymond threw himself into his work with the zest of a convert eager to prove his new faith:

> One of the first things we did at the new laboratory was fix a Yagi antenna and point it at the Radlab nearby, and radiate 10Kw of power on 30 MHz. Up to that time all of the radars designed at the Radlab had the same IF [intermediate frequency] of 30 MHz, which we thought was simply inviting jamming on that frequency from the enemy. Radlab took the hint, and the first effect the RRL had on the US war effort was to cause our radar people to design and build very well-shielded IF amplifier stages for their sets.' (11)

Certainly this deliberate jamming would have reinforced the lessons from the 'Kill the ham!' incident mentioned by Win Salisbury in the previous chapter.

During this formative period, while the Radio Research Laboratory was still 'a solution in search of a problem', news began to filter through of an incident in Europe which brought home the importance of the type of warfare in which they were dabbling. On 12 February 1942, the very day Dr Terman had first taken up his new post at Cambridge, the German battle cruisers Scharnhorst and

Gneisenau had sailed through the English Channel in broad daylight, during a rapid passage from Brest in north-western France to Germany. The operation took place under the noses of powerful British forces and was a masterpiece of boldness, careful planning and tight security. Aside from the British mistakes on that day, an important element in the success of the operation was the large scale use of ground jammers by the Germans. As the warships came within range of the British coastal radars at the eastern end of the Channel, these jammers were switched on simultaneously. Many of the best British radar operators, those who had already encountered jamming from the enemy in the summer of 1940, were now serving in the Mediterranean theatre where the heaviest fighting was taking place. Those who replaced them at the radars along the south coast of England had never seen previously heavy jamming, and reported the clutter on their screens as 'equipment failure' or 'local interference'. As a result British commanders did not appreciate the true significance of the radar operators' difficulties until it was too late. All of this came out during the far-reaching official inquiry after the event. (12)

Dr George Haller was assistant chief of the US Army Forces Communications Laboratory at Wright Field when the German breakout took place. He told the author:

> The details of the operation were slow in coming through, but before long we learned that the Germans had successfully used radar jamming to blot out the radars along the south coast of England to assist the passage of their warships. Before that I, personally, had never even given a thought to the idea of radar jamming. Here, then, was a completely new weapon which our

> enemy had demonstrated he was able to use against us. At the time, I remember, I found the prospect quite frightening. (13)

After he received news of the German success Dr Terman redoubled his efforts to get things moving at the RRL; who could know when and where the enemy might next employ this new form of warfare? He recalled:

> To find out more about what could be done I went over to England in April 1942, with Captains Finch and Detzer of the US Navy, and stayed for about six weeks. It was a highly fruitful visit. The British looked after us very well and showed us everything we wanted to see. I was invited to lunch with Sir Henry Tizard, one of their top scientists who was one of Mr Churchill's personal advisors on scientific matters. We were taken to the Telecommunications Research Establishment at Swanage where we saw a lot of Dr Robert Cockburn, the oracle at that time on radio and radar countermeasures [Cockburn's organization had produced the jammers which had successfully countered the German Knickebein navigational system in 1940]. And we visited the Admiralty Signals Establishment near Portsmouth. The British treated us as very important people who could be of great potential help to them.
>
> When I arrived back from England, in June, I had a much clearer idea of what we should be doing at RRL. Like us, the British knew nothing about Japanese radar. But they had a lot of information on what the Germans were doing. There were two main types of radar in large scale service with the German forces: the Freya, which worked on 125 MHz, and the Wuerzburg which worked on 560 MHz. So at Cambridge we started work to produce jammers to counter each of these frequencies. We did not wait for any formal request from the military before we began work. We took the view that if the military had to ask us to begin a research project, we had failed! It was our job to foresee what was needed and what we could do, not wait for them to tell us. (14)

Now that he had a clearer view of his goals, Dr Terman divided his group into four main sections: one under John Byrne was to work on a jammer code-named Mandrel to counter the 125 MHz Freya radar; one under Bob Sorrel was to work on a jammer code-named Carpet to counter the 560 MHz Wuerzburg flak control radar; one under Don Sinclair was to work on developments of the SCR-587 intercept receiver; and one under Clark Cahill was to investigate the vulnerability to jamming of current and future US radars.

The type of jamming used during the pre-war tests in England, and by the Germans in combat, had been of the pulsed or synchronized pulsed type. This produced a 'picket fence' pattern on the A-scopes of the radars then in use, but between the 'spikes' of jamming a trained radar operator could continue to plot targets. During investigations in England to determine the best type of modulation for jamming radars, Dr Cockburn realized that the receivers of the early radars were working close to the limits of their effectiveness: the feeble echo signals from an aircraft could only just be distinguished against the background of atmospheric 'noise'. So, Cockburn reasoned, if additional background noise could be introduced into the receiver via the aerial, all but the strongest aircraft echoes would be concealed. From this, it followed that the best way to counter an enemy radar would be to radiate powerful signals on its frequency modulated with random noise (15). Like so much truly original thinking, in retrospect this concept seems obvious enough; but at the time this was not the case. Cockburn's discovery was to form the basis for radar noise jamming as we know it. When Terman visited England, Cockburn made available his work on the theoretical analysis of noise jamming and this would influence the design of jammers at RRL.

II

At this point in the late spring of 1942, as Dr Terman was deciding which enemy radars his laboratory would attempt to counter and how, let us take a brief look at the operational deployment of radar in the German and Japanese armed forces (more comprehensive accounts of the evolution of radar in German and Japan, respectively, are given in Appendices E and G).

The German radar equipment produced in the greatest numbers was the 125 MHz Freya early warning set, deployed throughout metropolitan Germany and occupied Europe. This was the type of radar whose signals Derrick Garrard had picked up using the Hallicrafters S.27 receiver on the back seat of his car. Now the search for these radars sited inland was one of the tasks of Elintmodified Wellington bombers of No 109 Squadron of the Royal Air Force, also using Hallicrafters receivers. (16)

The next most numerous German radar was the 370 MHz Seetakt, used for coastal search and gunnery control and fitted to most of of the larger German warships. (17)

The third type of the German radar in large-scale service was the 560 MHz Wuerzburg, used for flak and searchlight control and as a heightfinder at some Freya sites. For its day this pencil-beam radar was extremely advanced. Its importance had been fully appreciated by the British intelligence service, and the first to be accurately located was photographed from a reconnaissance Spitfire at St Bruneval on the north coast of France. On 28 February 1942 British paratroops mounted a daring operation to capture the radar, and the attack was a complete success. The raiders returned to England with the aerial element, receiver, receiver amplifier, modulator, transmitter and one of the operators. The information resulting from the St Bruneval raid would play an important part in assisting the US jamming offensive against Wuerzburg later in the war. (18)

For the ground control of night fighters the Luftwaffe had recently introduced the Giant Wuerzburg, a set electrically similar to the normal Wuerzburg but with an aerial reflector dish enlarged from 10 to 25 feet to give a finer beam and increased range. (19)

For airborne use three German radars were in the service test stage: the 490 MHz Lichtenstein for night fighters; and the 120 MHz Rostock and the 180 MHz Neptun for maritime patrol aircraft. (20)

In 1941 the Japanese Army completed development work and had begun deploying a bistatic electronic interference detector system, similar to that tested before the war by the US Naval Research Laboratory. The Japanese system was designated the Type A Detector; it was a continuous wave device with separate transmitter and receiver operating on frequencies between 40 and 80 MHz, radiating up to 400 watts. The greatest range over which a pair of Type A Detectors was deployed was between Formosa and Shanghai, a distance of more than 400 miles, and it must be recorded that this was the first-ever example of an operational over-the-horizon radar. The device was able to indicate only the presence of aircraft flying somewhere between the transmitter and the receiver, however; it could give no information on their range, altitude, heading or the number present. (21)

During the spring of 1942 the Japanese Navy had begun to deploy a 100 MHz ground early warning radar, designated the Mark I Model 1. Soon afterwards an equivalent Japanese Army set appeared, the Tachi-6 which operated on single frequencies in the band 68 to 80 MHz (22). The Navy pushed ahead with a shipborne radar and in March of 1942 the first of these, the 200 MHz Mark II Model 1 for surface search and gunnery control, began sea tests on the battleship Ise. It is interesting to note that the Japanese had developed the high powered magnetron independently and in the spring of 1942 their first microwave radar, the 3,000 MHz Mark II Model 2, was ready for service tests on the battleship Hyuga. (23)

At this time the Japanese had no radar for searchlight or anti-aircraft fire control. Examples of the SCR-268 radar, and documents on the British 'Elsie' searchlight control radar and the Gunlaying Mark II set, had however been captured during the initial advances by Japanese forces. New types of radar based on these were under development, but none was yet ready for service. The Japanese were also working on a surface search radar for patrol aircraft, but it was not yet ready for production either. (24)

Of the enemy radars the German Freya, Seetakt and Wuerzburg sets were well known to British intelligence by the spring of 1942; and initial reports had been received on the Giant Wuerzburg. This information had been passed to the US intelligence services, and from there to Dr Terman's laboratory. Nothing was yet known in Great Britain or the USA of the other German radars, or of any of the Japanese sets.

III

Soon after Dr Terman's return from England in June 1942, the time came for the Radio Research Laboratory to move away from Cambridge as planned at its inception. Terman told the author:

> Karl Compton, the president of MIT, returned from one of the NDRC monthly meetings and telephoned news of the decision to me: "Beginning yesterday afternoon at 4 o'clock, you became a Harvard man!", he said. So it came about that we moved into a wing of the Biological Laboratory on Divinity Avenue at Harvard, which would be our home for the rest of the war. (25)

The move to Harvard went relatively smoothly and as the Radio Research Laboratory staff settled into their new quarters, work resumed on the development of countermeasures equipment. Bill Rambo described the work in the transmitter group:

> Following my initial introduction and the move to Harvard, the first job they gave me was to build an RF oscillator - jammer is too strong a word - to operate on the 560 MHz frequency of the German Wuerzburg radar, using components that were readily available. In this I worked under the guidance of Bob Sorrel, the leader of the transmitter group. The best tube

> then readily available was the Western Electric "doorknob" tube (so named because of its shape), but the frequency required was close to the limits of its capability. I was greatly encouraged to be able to light a tiny flashlight bulb with the ¼ watt output from my oscillator.
>
> I moved on, constructing bigger and better oscillators to operate at 560 MHz - the step from ¼ watt to ½ watt might not sound like much, but it was a 100 per cent increase! Eventually we managed to get 5 watts from a couple of doorknob tubes in push-pull, and these powered the APT-2 Carpet jammer. Better tubes began to emerge from General Electric, Westinghouse and IT&T. We had a very good liaison with the tube manufacturers, and their representatives would bring us their latest hand-made prototypes. (26)

At the same time, Clark Cahill's counter-countermeasures group began running tests to determine how effective enemy jamming might be against some of the radars used by the US forces. O.G. 'Mike' Villard worked with Cahill and he remembered:

> We installed a couple of radars on the top of the RRL building and tried various forms of jamming against them: a US Army SCR-268 searchlight and gun control set, and a British ASV Mark II airborne radar used for the detection of shipping. Both of these first-generation radars proved painfully easy to jam.
>
> Although there was little that could be done to reduce the radars' vulnerability to noise jamming, we did devise some fixes to enable them to stand up to the less-effective jamming signals. For example, in the SCR-268 the detector was DC coupled to the following video amplifier tube. As a result even a little CW jamming was enough to bias off or completely overload the video amplifier. The obvious remedy was to put in capacitive coupling, which stopped this particular form of overloading. On our recommendation I believe this simple modification was ultimately incorporated into all SCR-268's.
>
> Our findings on the effects of the various types of jamming were passed to the radar people at the Radiation Laboratory at MIT, with the result that the newer sets were designed - to the extent that was possible - to be less vulnerable to enemy interference. Furthermore, by their very nature the new microwave radars then being developed were considerably more difficult to jam than the early long wave radars had been. (27)

In the receiver group progress was also rapid. Dr Joseph Pettit joined the RRL just before the move from Cambridge, immediately after received his doctorate in electrical engineering:

> Once I knew enough to be employable, I was assigned to the receiver group under Don Sinclair. Then, soon after I started, Sinclair had to return to General Radio and I was appointed head of the group. The first project I was involved with was the SCR-587, and airborne Elint receiver to cover the frequency band 100 to 950 MHz. By today's standards it was a fairly crude superhet device, and required one to twiddle a couple of knobs in order to bring in a station. Once we had made it work we handed it over to Philco, who produced it in small numbers. (28)

The big drawback of the SCR-587 was that it did not have single-knob tuning, which restricted its value as an Elint receiver. So the next step was to re-design it with single-knob tuning, and with a few other improvements such as stagger tuning to increase the bandwidth of the intermediate-frequency amplifier it became the APR-1.

A further aspect of the work at RRL was a series of experiments with the use of metal foil to jam radars, the technique later named 'Chaff' in the USA and 'Window' in Great Britain. Dr Terman had first heard of this method during his visit to England, where experiments had been conducted with large oblongs of foil unrelated to the wavelength of the radar to be jammed. Terman passed details of what he had learned to Win Salisbury, who began experimenting with resonant lengths of foil hand-rolled into cigarette-section cylinders to make them effective over a broad spread of frequencies. During July 1942 he tested these cylinders against one of the MIT laboratory radars near Boston, dropping them from an old B-18 bomber flying out of East Boston (now Logan) airport. (29)

While tests of the foil strips were taking place in the USA, others were being mounted in Germany and Great Britain. In each country the initial conclusion was similar: the countermeasure was devastatingly effective against precision radars operating on frequencies between about 200 and 600 MHz; if dropped in sufficient numbers, the strips produced scores of spurious echoes on the radar screens and made the tracking of aircraft almost impossible. In each country the most stringent steps were taken to prevent the enemy learning of this countermeasure, including the postponement of its operational use unless or until counter-countermeasures could be developed. In Germany Reichsmarschall Hermann Goering personally banned all further testing of Dueppel, as the foil strips were known there (30). In Great Britain Lord Cherwell, Mr Churchill's chief scientific advisor, allowed tests with 'Window' to continue but only with the strictest security safeguards (31). In the USA the Navy ordered a halt to the tests at the RRL, and enforced this with armed marine guards posted around Salisbury's B-18 at East Boston airport. Following this, work on the countermeasure in the USA ceased for some months. (32)

IV

During July and August 1942, the Radio Research Laboratory received a valuable transfusion of skill in the shape of the Columbia Broadcasting System team which had been working to develop colour television. This work was not related to the war effort, and after some discussion Dr Terman was able to persuade the Vice-President of CBS to allow the team to transfer to the RRL. As well as furthering the nation's war effort, Terman stressed that this would enable the team to keep abreast of the latest developments in electronics and this would almost certainly be useful to the company after the war. Some of the team came to RRL direct, others worked in the CBS laboratories on projects for RRL. In this way Terman secured the services of several notable experts including Dr Peter Goldmark who was one of the leading experts on television (and who would develop the long-playing record after the war), and John Dyer who had served as chief radio engineer on Byrd's expedition to the Antarctic in 1933 (33). The youngest member of the team was Eugene Fubini, son of the famous mathematician Enrico Fubini.

V

By the second week in August 1942 Dr Terman could look back on six months of solid achievement, since the day in February when he had taken the first tentative steps to fulfill the rather vague commission he had accepted from Lee DuBridge. Now the Radio Research Laboratory was firmly established at Harvard, it had more than 170 capable and enthusiastic engineers and staff and was still growing, and the various research groups were working towards clearly defined goals. As yet no RRL-initiated countermeasures equipment was ready for production but it would not be long before production could begin.

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CHAPTER 3 NUDGING TOWARDS BATTLE

While Dr Terman had been establishing and expanding the Radio Research Laboratory during the spring and summer of 1942, people in other organizations were also engaged in work which would play an important part in the countermeasures story.

Although RRL was responsible for co-ordinating the development of radio countermeasures for all four US armed services, the Naval Research Laboratory at Anacostia continued with its own work in this field while maintaining a close liaison with Dr Terman and his team. Following the heavy losses of shipping during attacks by German U-boats off the east coast of the USA and in the Atlantic, there was an urgent requirement for an effective high frequency direction finder for convoy escorts, to enable them to locate enemy submarines when they transmitted. As the official US Navy historian later wrote:

> Although the shore HF/DF stations were of inestimable value in locating submarines in time to divert the routing of convoys, or to warn them of enemy presence, the necessary delay in receiving their reports made it highly desirable to install HF/DF on escorts. (1)

Working under NRL auspices, the expatriate French engineers at the ITT Laboratory at Amangansett made considerable progress with their shipborne instantaneous high frequency direction finder. By the spring of 1942 it was ready for sea tests. On 26 March two of the French engineers, Maurice Deloraine and Henri Busignies, attended a conference at the US Navy Bureau of Ships to discuss the installation of the new device on warships. Numerous senior officers were present. Later Deloraine wrote:

> After being questioned about our ability to deliver a shipborne HF/DF, we were asked where we wanted to place the antenna. This was a critical question, clearly entirely Busignies' responsibility. He pointed to the top of the highest mast and said: "This is your radar antenna is it not?" Yes was the answer. "Then I propose you remove it and we place our antenna there instead." I thought we were going to be thrown out of the room, but they agreed to do it. (2)

The acceptance that the aerial of the high frequency direction finder could replace even that of the radar on the covetted masthead position, illustrates the regard with which the new device was held. The meeting decided that the direction finder should undergo sea tests on the destroyer USS Cory. These proved successful, and the device went into production designated the DAQ. For a time it was US Navy policy that half of its destroyers should be fitted with HF/DF aerials at the top of the mainmast and the other half would carry radar aerials there. But before this was implemented a better solution was found: all new-construction warships of this type were fitted with two masts, which allowed the aerials for both equipments to be carried high above the rest of the vessel. (3)

II

A further move in the spring of 1942, which would later have an important bearing on the countermeasures story, was the establishment of the Army Air Forces airborne radar school at Boca Raton near Fort Lauderdale in Florida. To ease the problem of accommodation the War Department secured the lease of the palatial Boca Raton Club nearby with 650 rooms surrounded by two golf courses, six tennis courts, swimming pools, beaches and beautifully landscaped gardens. It did not take long, however, for the military to send in so many people that most semblance of luxury disappeared with the overcrowding usual at service facilities in wartime (4). At Boca Raton students were taught to service and operate the metric-wavelength radars fitted to maritime patrol aircraft and night fighters, the microwave SCR-517 for patrol aircraft and the British GEE medium range hyperbolic navigational system. Airborne instruction in operating the radars took place in aircraft flying from Morrison Field, near West Palm Beach. At the end of the three-month course, graduates were qualified to command airborne radar maintenance shops. (5).

III

The successful passage of the German battle cruisers through the English Channel in February 1942 had given a powerful boost to the development of electronic countermeasures in Britain, just as it had in the USA. One of the first devices which resulted was code-named 'Moonshine': an airborne pulse repeater to operate against German Freya early warning radars working in the 125 MHz band. Triggered by the pulse from the enemy radar, Moonshine replied with a wide-pulse signal corresponding to a concentration of aircraft up to five miles in depth, amplitude modulated so that it had the beating and interweaving characteristic of an echo returned by several aircraft flying in close formation. One Moonshine aircraft was necessary to cover each Freya radar to be spoofed, so during an operation several such machines would be used. (6)

During the late spring of 1942 No 515 Squadron of the Royal Air Force received nine Defiant two-seat fighters fitted with Moonshine. On 6 August the Squadron flew its first test feint operation, when eight Defiants staged a Moonshine 'demonstration' over the English Channel near Portland. An estimated 26 German fighters took off from bases in north western France in readiness to engage the 'raiders' and the Cherbourg balloon barrage was raised. To confirm Moonshine had caused the reaction, six days later the same aircraft flew the same mission but with their repeaters switched off; no enemy fighter activity was observed and the Cherbourg balloons stayed down. (7)

The availability of the Moonshine squadron coincided with the initial attack by B-17 Flying Fortresses of the US 8th Air Force in England. On 17 August the 97th Bomb Group sent twelve B-17's to bomb the rail yards at Rouen in France. Two feint attacking forces, each with three B-17's, flew ahead of the main raiding force. One feint headed west towards Alderney in the Channel Islands, about 150 miles west of the target; the second feinting force headed towards Dunkirk, 120 miles north-east of the target. Flying with the easterly feint were all nine Moonshine Defiants, plus 97 Spitfires arrayed as escorts to give the spoof realism. Both feinting forces flew to within ten miles of the enemy coast, then turned around and went home. The British report on the action noted that an estimated 150 German fighters took off to engage the threatened attack on Dunkirk, but failed to intercept:

> This operation stirred up German reaction on a considerable scale. Aircraft of the N. Section of the Pas de Calais were airborne by 1720 and the recall to one wing was heard at 1747. The raiders were designated as bombers, main formation, second formation, and withdrawal cover. An announcement sent out by control at 1730, and notable for its departure from the usual jargon, reported bombers at 2/3,000 feet, covered by fighters in serried mass. Control's analysis of the attacking force was not clearly laid out: the formations were often inaccurately labelled and it was only in the latter stages that control avoided confusion by concentrating on the movement of only one of the formations. (8)

Meanwhile the real attacking force, escorted by more than 170 Spitfires of the Royal Air Force, was able to bomb Rouen and return with no bombers lost or damaged to fighter attack. About 80 German fighters attempted to engage the B-17's but only one was able to get through the escorts and approach the bombers, and it inflicted no damage.

Initially the Moonshine feints were successful in drawing German fighters away from the American daylight bomber formations; but as the Luftwaffe deployed more and more Freya and Wuerzburg radars in Western Europe the tactic became progressively less effective. Moreover, in the autumn of 1942 the B-17's began to penetrate deeper into occupied territory and from visual sighting reports the German fighter controllers had little difficulty in establishing which attacking force was the real one. No 515 Squadron flew its final Moonshine feint in support of an 8th Air Force operation in October 1942. (9)

Probably the most significant result of the Moonshine operations was that they gave the 8th Air Force planners an insight into the advantages of using radar countermeasures to support attacks. Although there is no proof, it is likely that this helped establish a military requirement for the first RRL-designed jammers when they became available a few months later.

In the final months of 1942, during attacks on targets near the coast of occupied Europe, the US heavy bombers often used low altitude approach tactics to remain unseen by the German radars for as long as possible. Typical of such attacks was that on 9 November against the U-boat base at St Nazaire in western France. The raiding force, comprising thirty-three B-17's and thirteen B-24's, flew from their bases in eastern England to Lizard Point at 2,000 feet. As they left the coast the bombers descended to 500 feet to remain beneath the German radar cover. Sweeping round in a wide arc out to sea just outside the enemy radar cover, the raiders remained unseen until they were within 50 miles west of the target. Then they climbed to their attack altitudes between 6,000 and 10,000 feet and entered their bomb runs. No German fighters contested the incursion, but there was accurate and intense Flak which caused the destruction of three bombers and damage to 23 others. (10)

Meanwhile, unknown to the 8th Air Force, US bombers had already started to jam the German Freya early warning radars. The

SCR-522 VHF radio fitted to the American aircraft caused interference on Freyas in the area, if the radio channel in use was close to the latters' operating frequencies. The matter was discussed by the Luftwaffe during a routine conference on equipment held at the Reich Air Ministry in Berlin on 5 January 1943. Engineer Colonel Dietrich Schwenke, head of intelligence on enemy equipment in the west, revealed that a Norden bombsight had been recovered intact from a B-17 which had recently come down in France; then he informed the meeting:

> A test has been conducted with the American VHF radio, which has shown beyond doubt that this equipment can cause interference on the Freya radar. It is entirely possible that the jamming [previously experienced] on this frequency is deliberate, or it might be accidental. The previously reported instances of the jamming of Freya can be traced back to this cause. (11)

General-Feldmarschall Erhard Milch, head to the Luftwaffe equipment procurement organization, asked if it was possible that German VHF radios caused similar interference to Allied radars. Schwenke replied that, theoretically, it was possible (in fact the FuGe 16, the standard German aircraft VHF radio, used the 38 to 43 MHz band where there were few Allied radars operating; so there was little opportunity for the Luftwaffe to retaliate in the same way). (12)

The jamming of Freya by the SCR-522 was accidental. One interesting point is that, just as the US forces failed to realize that it was happening, the Germans failed to appreciate that Freya, in its turn, was causing interference on the SCR-522. But during this period US aircrew returning from operations over Europe often complained of severe interference on certain of their VHF channels; the cause of the interference was soon linked with the Freya, through no further conclusions were drawn at the time.

IV

During October 1942 there was a major reorganization of the lines of authority between the Radio Research Laboratory and the National Defense Research Committee. Previously the RRL had been part of the NDRC's 'F' Committee which was concerned mainly with the development of radar. Now Dr Terman's laboratory had a strength of 205 people of all grades of which 78 were engaged in research; and it was still expanding as fast as the intake of qualified engineers would allow (13). The NDRC decided to expand the radio countermeasures development effort into a full Division, which would later take control of new facilities beyond those at Harvard. The man chosen to take overall charge of the division was Dr Guy Suits, until then the Assistant Director of the General Electric research laboratories at Schenectady, NY. Suits told the author:

> Dr Vannevar Bush, head of the NRDC, contacted General Electric and asked if I could be made available to head the new division. General Electric asked Bush to contact me direct for my feelings on the matter and after a chat I agreed to take the new post. At that time I knew the meaning of the term "radar countermeasures", but that was about the limit of my knowledge on the subject.
>
> In October 1942 I took up my new post as Chief of Division "F", soon afterwards re-named Division 15, of the NDRC. I found Vannevar Bush a tremendous man to work for. An older and much respected scientist, he had excellent relations with the President and Congress. When he went before a Congressional Committee asking for funds he was very convincing and almost always got what he asked for. If he didn't he would sometimes have a word with the President and get what he wanted that way. To operate a large civilian organization to control war work in wartime, when there were already the armed services who were supposed to do all of that, and at the same time main-

> tain good relations with those services and Congress and the President as well, you almost can't do that. But Bush did.
>
> Getting financial support from the NDRC was never a problem, they gave us the utmost co-operation. All we had to do was convince them we had an opportunity worth supporting - and they were always looking for worthwhile opportunities into which to channel their funds. When we wished to make a proposal or there was the annual budget review I would go along with Terman and some of the department heads and we would describe what we were doing, what additional resources we felt were necessary and what it would cost. And almost without exception they accepted the figures we gave them. I don't recall that they ever said anything like "You're getting out of hand here, we'll cut your request in two," as so often happens in industry. (14)

Suits saw his role as being supportive of Terman, to manage some of the other activities outside the RRL and smooth the latter's path by supplying whatever resources were needed to expand the Harvard organization.

In parallel with the work at Harvard, the RRL sponsored research at outside laboratories. Some of the most important at this time was undertaken by the Bell Telephone laboratories, where Dr Knox Black developed techniques for jamming enemy radio communications systems. In the event there would be no major requirement for such jammers by the US armed forces; their use would have hindered the collection of signals intelligence and, as was revealed only long after the war, the Allies had succeeded in breaking into the German and Japanese code and cypher systems and placed great reliance on information obtained in this way. The stubborn refusal of the military to use communications jamming on a large scale did not, of course, lessen the technical value of Black's work. But the decision to adopt this course would be a source of considerable frustration to Black and his team. (15)

V

With the development of equipment to counter the German radars now progressing rapidly, we shift our attention to the unfolding pattern of events in the Pacific. From there, in the summer of 1942, came the revelation that the Japanese, too, had a radar capability that could not be ignored.

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CHAPTER 4 PACIFIC ELINT

During the eight months following the Japanese attack on Pearl Harbor on 7 December 1941, there was no serious attempt by the Allies to discover whether enemy forces in the Pacific theatre were using radar. For most of that time the available Allied troops and equipment had to be thrown into battle piecemeal to halt the Japanese advance. There was no time or effort to spare to investigate devices the enemy might be using. Only with the decisive victory over the Japanese aircraft carriers during the Battle of Midway in June 1942 were US forces in the Pacific able to secure a breathing space. But then, it is clear with the easy superiority of hindsight, a piece of circular logic prevented the hunt for enemy radar signals: because no serious search had been made for such signals, there was no information on enemy radars; and because there was no information on enemy radars, there were no demands for a search for their signals.

This state of cosy ignorance came to an abrupt halt on 7 August 1942, when US Marines stormed ashore at Guadalcanal in the Solomon Islands and seized the partially completed airfield there. To one side of the construction site marines found a box-like operating cabin topped by a bedspring-like structure: a Mark I Model I early warning radar (1). Immediately, the captured set was shipped to the Naval Research Laboratory at Anacostia and restored to working order. Lieutenant Ralph Clark, assigned to Navy Bureau of Aeronautics, was one of those who examined it:

> I had a look at it and I remember being impressed how crude it was compared with our own early sets - and Goodness knows, our first generation SCR-268, -270 and -271 sets were crude enough! Nearly all the tubes in the Japanese equipment appeared to be copies of types made by General Electric. (2)

The chance capture of the Japanese early warning radar on Guadalcanal caused a flurry of excitement and pointed out the need for an electronic reconnaissance effort in the Pacific theatre: if the enemy had one radar there were undoubtedly others, and Allied commanders needed to know about the types, numbers and capabilities of the enemy sets.

At the NRL Dr Robert Page and his team began work to design and hand-build a few examples of a crystal-type intercept receiver suitable for airborne or shipborne use, the XARD (approximate effective cover 50 to 1,000 MHz). At the same time Dr Guthrie of the same organization began work on a suitable jamming transmitter (3). Early in September six Petty Officer radiomen were selected for additional training to operate and maintain the new equipment. The men went to NRL and received two weeks' instruction on the XARD receiver and the associated airborne jamming transmitter (little is known of the latter, its frequency coverage is thought to have been approximately from 75 to 125 MHz). At the end of their hasty training the six were formed into a detachment designated Cast Mike Project 1 (CM for 'countermeasures'), and flown to Hawaii with their equipment. Chief Petty Officer Jack Churchill, newly promoted, took charge of the party and demonstrated the receiver and jammer at the Pacific Fleet Radar School at Pearl Harbor. Towards the end of

September he and Petty Officer Robert Russell left for the south Pacific war zone, taking with them some of their receivers and jammers. (4)

II

The brief stop-over of the Cast Mike 1 team was not the only event of countermeasures interest at Pearl Harbor in September 1942. The submarine USS Drum was also at the base, preparing for her third war patrol. Radioman Donald Vaughan, one of her crew, remembers that a civilian came on board and installed an ARC-1 radar intercept receiver (ARC-1 was the US Navy designation for the Army SCR-587 receiver; it should not be confused with the AN/ARC-1, the standard VHF transceiver equipment fitted to US aircraft during the latter part of World War II). (5)

On 23 September Drum left Pearl Harbor, and early in October arrived off the east coast of Japan where she sank three freighters. At this time there were insufficient US submarines to detach one solely for Elint work and Drum's primary mission was to seek and destroy enemy shipping. The boat took no special action to search for enemy signals, and Vaughan's orders were to operate the receiver only when he was not otherwise engaged. The submarine carried no special aerials for the intercept receiver, the operator had to wire the set to one of the boat's normal communications aerials. (6)

As Drum cruised off the Japanese coast Vaughan remembers logging a few enemy radar signals. When the boat returned to Pearl Harbor early in November, his log aroused considerable interest (7). With the passage of more than forty years Vaughan does not remember details of the signals he picked up nor, despite an intensive search, has it been possible to find written or verbal evidence to support his account. In view of the secrecy that would have surrounded such a venture, however, it is not surprising that confirmation has been difficult to find. Because Don Vaughan could well have been the first US serviceman ever to detect signals from an enemy-operated radar on a search receiver, his uncorroborated account is included in this history.

III

While Drum cruised deep into enemy waters, Jack Churchill and Bob Russell of the Cast Mike 1 team arrived at Headquarters COMAIRSOPAC (Commander Air South Pacific) at Espiritu Santo in the New Hebrides. They installed an XARD receiver in a B-17E Flying Fortress of the 11th Bomb Group, Army Air Forces. The pair had also brought with them a few of the NRL-built radar jammers, but until enemy radar signals were found these were to be held on the ground ready for installation. One of the Navy men was to fly with the bomber to operate the XARD, doubling as a gunner if the aircraft came under fighter attack. (8)

Jack Churchill flew with the first B-17 Elint mission on 31 October 1942, a reconnaissance flight of over 11 hours from Espiritu Santo to Guadalcanal and Bougainville, and back. As in the case of USS Drum's patrol to Japan, the bomber flew a normal mission with no deviations to look for enemy radar signals; none were found.

During November 1942 Churchill flew on seven long range reconnaissance missions to the Solomons and New Britain in the B-17, staging through Henderson Field on Guadalcanal on three occasions. On the 25th the aircraft found and bombed Japanese warships off Rabaul and Bougainville, and had a skirmish with enemy fighters. But still no enemy radar signals were detected. (9)

We now move away from the Pacific, to observe related events taking place elsewhere. But before leaving this theatre it is worth noting that, in spite of the delays in starting Elint operations in the Pacific area, by modern standards events had still moved relatively quickly. The reconnaissances by USS Drum and the Cast Mike 1 team had begun within ten months of the Japanese attack on Pearl Harbor and within a little over two months of the capture of the enemy radar on Guadalcanal.

IV

With the Radio Research Laboratory at Harvard preparing its first airborne countermeasures equipments for production in the autumn of 1942, the Army Air Forces for whom most of the devices were intended lacked any aircrew trained to operate them. Major Mel Jackson journeyed from the Army Air Forces headquarters in Washington to the radar school at Boca Raton to investigate the possibility of starting a radio countermeasures course there. Jackson discussed the course with Lieutenant Colonel Monte Canterbury and Lieutenant Hugh Winter, two officers on the staff of the school. (10)

Following the visit Hugh Winter established a radio countermeasures course at Boca Raton, based on a syllabus he drafted with Jackson. For security reasons the four-week period of instruction became known simply as 'Hugh Winter's Course'. The first such course began on 2 November 1942 with four students: 2nd Lieutenants Edward Tietz, William Praun, Philip Rousculp and Rudolf Arndt, all of whom had been trained in airborne radar at the MIT and Boca Raton. The countermeasures course provided the students with a theoretical background to the new subject and some practice in operating the SCR-587 receiver on the bench. Upon successful completion of 'Hugh Winter's Course', the graduates were awarded flight status as radio observers. (11)

While the initial intake of students was going through the new course at Boca Raton, there was a further development in the countermeasures war in the Pacific. Following a reconnaissance of the Japanese-occupied island of Kiska in the Aleutians, an Army Air Forces aircraft returned with photographs of a pair of unusual structures at one of the enemy positions (12). It was thought the 'structures' might be radar sets, and the obvious way to confirm this was to fly an aircraft carrying one or more intercept receivers through the area. As we have seen, one such aircraft was already operating in the south Pacific; but it is not clear whether Jack Churchill's efforts were known at the Army Air Forces Headquarters. At any event, that service now to embarked on a separate and more ambitious crash programme to modify an aircraft for the Elint role in the north Pacific theatre.

In November 1942 Major George Haller, the Assistant Chief of the Army Air Forces Aircraft Radio and Communications Laboratory at Wright Field, received a visit from Lieutenant Colonel James McRae from the Pentagon. The pair discussed the latest intelligence on Japanese radar, and how a suitable aircraft could be modified for the Elint role. Haller said his group could do the installation work, using receivers already available or which could be rapidly modified for the task. The informal discussions complete, McRae returned to Washington where he drafted an appropriate letter for the signature of General 'Hap' Arnold, Chief of Staff of the Army Air Forces. A few days later Haller's boss, Colonel Yeager, dashed into his office in a flurry holding the letter signed by the General. He told Haller to drop everything else and give top priority to the work of install-ing the receivers into the aircraft. The project was code-named 'Ferret'. Yeager had no inkling of McRae's earlier visit, and no doubt was impressed with his subordinate's immediate grasp of was required! (13)

A B-24D Liberator was allocated for the new role and conversion began. Lieutenant Ralph Clark from the Naval Research Laboratory was one of those summoned to Wright Field to assist. He recalled:

> Around Christmas 1942 a crash-program at Wright Field fitted a B-24 with the necessary receivers for a radar search of the Aleutians. I spent a week at Wright as we [the Navy and NRL] supplied most of the equipment. As well as an SCR-587 modified to tune down to 30 MHz, we fitted a Hallicrafters commercial receiver [an S.27], homing antennas and a breadboard model of a pulse analyzer built by the Naval Research Laboratory. (14)

Two graduates from 'Hugh Winter's Course' at Boca Raton were assigned to the crew of the Ferret B-24: 2nd Lieutenants Ed Tietz and Bill Praun. After a briefing at the Pentagon, the pair went to Wright Field to familiarize themselves with the equipment being fitted to the aircraft.

Early in January 1943 the work on the intercept receiver installation was complete and the aircraft went to Fort Worth, Texas, to have its engines modified for cold weather operations. Next, the two operators tried out their receivers against radars along the west of the USA. At the beginning of February the B-24 Ferret flew to Adak in the Aleutians, its base for the planned Elint operations. But then the weather closed in, and for much of the month that followed air operations were impossible. (15)

On the morning of 6 March 1943 the Ferret B-24 took off from Adak and headed eastwards towards Kiska. Manning the intercept receivers, Ed Tietz and Bill Praun soon picked up the signals they were looking for. Tietz remembered:

> We heard the signals in our earphones of a 100 MHz radar scanning at a steady rate. They sounded just like the signals from the search radars I had listened to during our training flights over the USA. No different at all. (17)

During the flight the two operators picked up transmissions from two Japanese radars close together in the frequency spectrum, both Mark I Model 1's similar to the set captured on Guadalcanal. Having measured the radars' frequencies, Tietz and Praun used their primitive analyzer to determine the pulse width and repetition frequency of the signals. Then the crew set out to measure the volume of coverage of the sets with a series of circuits around the island at different altitudes. The operators noted where the enemy radar signals faded out and faded in, and passed these to the navigator who plotted them to discover the 'holes' in the enemy radar cover. Those readers familiar with modern radar Elint techniques will, no doubt, recognize the professionalism displayed during this, one of the first ventures by US personnel in this field. Although the operation had been planned from first principles, Ed Tietz and Bill Praun worked systematically to achieve their goal. The initial mission by the B-24 Ferret lasted about five hours, nearly half of which were spent in circling Kiska. (17)

During two further Ferret missions, on 7 and 15 March, Tietz and Praun further refined their picture of the Kiska radars' coverage. In the course of one of these flights the B-24 extended its search to the Japanese-held islands of Attu and Agattu to the west of Kiska, to determine if there were enemy radars there; no signals were heard coming from either island. During the mission on the 7th a Japanese floatplane flew in formation with the Ferret aircraft for several minutes at a respectful distance, then broke away without attempting to attack. (18)

After their third mission the Ferret crew drew up a contour map of the area around Kiska showing the coverage of the radars, and passed this to 11th Air Force headquarters at Adak.

Its initial mission in the Aleutians complete, the Ferret B-24 returned to Wright Field. Tietz and Praun reported their findings Major Mel Jackson at the Pentagon, then went to the Radiation Laboratory and RRL for further debriefings. The first full-hearted US venture into the field of Elint had achieved all that could reasonably have been expected of it.

V

At the same time as the Army Air Forces' Ferret missions were being prepared and flown, the less ambitious Cast Mike 1 operations continued in the south Pacific. In December 1943 Jack Churchill started flying the XARD receiver in PBY-5A Catalina amphibians of Navy Patrol Squadron VP-72, engaged in reconnaissance missions around the Solomon Islands from bases at Guadalcanal and Espiritu

Santo. Catalinas operating in the theatre flew mainly at night and were painted black, and were known as 'Black Cats'. Churchill continued the Elint operations through January, using B-17's and PBY's, but still failed to detect enemy radar signals (19). Whether this was due to a lack of enemy transmissions when the aircraft were in their area, or the shortcomings of the XARD receiver, is impossible to establish with certainty. Without doubt the XARD left a lot to be desired as an operational intercept receiver. It had been put together in a hurry, and it showed: the aerial fed a quarter-wave stub, and to search the frequency spectrum the operator had manually to slide a shorting bar up and down the stub; when he heard the buzz of radar signals in his headphones, the operator could read their frequency off calibrations on the stub. It was a crude system and in the Catalina - where the aerial and shorting stub had to be mounted above the operator's head - the XARD was at its worst. Douglas Roberts joined Churchill at Guadalcanal in January 1943, and had some harsh things to say about the XARD:

> It was a lemon! To tune it you had to reach up over your had to slide the tuning short up and down, there was no tuning knob. That may not sound too hard, but when you had to reach over your head to push that short up and down for about two hours, you thought your arm was going to fall off! Another problem was that the stub was silver-plated, and when it was exposed to the South Pacific humidity it started to corrode; when that happened, during tuning the receiver began to get "noisy". (20)

Early in 1943 Cast Mike 1 received a few ARC-1 receivers (Navy SCR-587's), which Douglas Roberts remembers as a considerable advance over the XARD:

> It was a vast improvement over the XARD. It had knob tuning which you had to turn by hand, but that was a lot easier than pushing that stub up and down above your head. (21)

VI

Despite the efforts being made to find it, information on Japanese radars remained sparse in the spring of 1943. One Mark I Model I early warning set had been captured on Guadalcanal, two more had been positively located on Kiska and one had been detected on Wake Island. In addition there was a smattering of information on similar radars on the Japanese home islands. A start had been made to Elint operations in the Pacific, but clearly there was a long way to go before Allied intelligence officers possessed a detailed picture of Japanese work in this field. In the mean time, events in the European and Mediterranean theatres were moving far more rapidly.

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CHAPTER 5 SKIRMISHES IN THE ETHER

While the initial Elint missions were being flown in the Pacific theatre, in Europe the Royal Air Force already knew sufficient about the enemy radar network to initiate a campaign of active countermeasures to support its night bombing offensive on Germany.

To counter the German Freya and Wassermann early warning radars operating on frequencies around 125 MHz, RAF bombers were fitted with the British 'Mandrel' jammer. (Although it was designed for the same function and carried the same code-name as the Mandrel [APT-3] developed at RRL, the British equipment was quite different from its US counterpart. Similarly the British Carpet jammer under development to counter Wuerzburg was quite different from the APT-2 designed for the same purpose at RRL (1). To avoid confusion the US jammers will be referred to by their code-names and the British jammers will be referred to as 'British Mandrel' and 'British Carpet' etc where appropriate in this account).

To further slow the reaction of the enemy defences Royal Air Force night bombers now carried 'Tinsel', a modification to their high frequency radio transmitters. A microphone fitted behind one of the engines could be used to modulate the transmitter, after it had been tuned to one of the German fighter control radio channels.

The Royal Air Force began using Mandrel and Tinsel in December 1942 and initially the losses during raids on Germany fell by about a third. The Germans reacted swiftly to the radar jamming, however, and in January 1943 a British monitoring station picked up signals from a Freya near Calais on the new frequency of 107.9 MHz. Thus began the extension of the Freya band to avoid jamming, to be matched by the extension of the frequency spread of Mandrel, which was to continue for the rest of the conflict. (2)

The opening of the British jamming campaign against the German air defences marked a significant milestone in the history of countermeasures. From now on jamming would be in almost daily use in support of air attacks, as a matter of routine; no longer would this form of warfare be confined to a few specialized operations. The genie was out of its bottle and nobody could push it back.

II

By the end of 1942 the APT-2 Carpet jammer was ready to go into production, but an unexpected problem prevented it from doing so: there was no official US military requirement for such a device. The Eighth Air Force operated over Europe only when clear skies were forecast at the targets and visual bombing was possible. But that meant German anti-aircraft gunners could aim their weapons using optical fire control methods. Jamming the Wuerzburg radar used to aim guns at night or through cloud would do little to reduce losses, the argument ran, so what was the point of putting Carpet into production? Fortunately Lieutenant Colonel James McRae, controlling procurement for the Army Signal Corps, was more far-sighted than many of his contemporaries (3). He saw the possibilities of Carpet, as RRL Associate Director Dr A. Earl Cullum remembered:

> He accepted our arguments that sooner or later the Army Air Forces would have a requirement for such a jammer, and on his own responsibility placed an order for a hundred. It was a brave decision and one which marked an important step in the development of countermeasures in the US. McRae deserves every credit for it, had someone higher up taken issue with him he could have been in deep trouble. Those initial Carpets probably cost about $5,000 each so the first hundred would have come to around half a million dollars. Today such a sum would be considered rather puny for a jamming program - it would probably not even cover the cost of the technical manuals - but in 1943 it was a horrendous amount of money to commit without proper authority. (4)

Fortunately a service requirement was soon issued for Carpet; McRae's head did not remain 'on the block' for long, and the initial order was raised to 200. By April 1943, in addition to the APT-2 Carpet, three other RRL-designed jammers had been placed in limited production: the APT-1 Dina, the APT-3 Mandrel and the APQ-2 Rug (for frequency coverage and other details, see Appendix C) (5). Thus by the early spring of 1943 development was complete and production had begun of jammers to cover the spectrum from 85 to 720 MHz, able to counter the vast majority of German and Japanese radars then in use or which would be introduced during the conflict.

The auto-search receiver designed by Peter Goldmark, known as the RC-160 at Harvard and later as the APR-2 by the US military, proved extremely difficult to produce even though there was a clear-cut service requirement for it. George Rappaport, one of those at the Aircraft Radio Laboratory at Wright Field responsible for getting the RRL-designed equipments into service, commented:

> This was a brilliant piece of design by Peter Goldmark, but initially it seemed to defy production. It caused us so many problems that one day Jim McRae suggested that was ought to get somebody to drop an RC-160 on Japan, then the Japs could spend the rest of the war trying to copy the receiver and get it into production! That remark did not endear us to Peter Goldmark! (6)

At the same time as its first jamming transmitters were being put into production, RRL continued to examine other ways of countering enemy radars. Although the demands of security had forced a halt to the tests with air-dropped metal-foil dipoles (Chaff) in the USA in the summer of 1942, Dr Terman was keen to continue research into this countermeasure. Accordingly he asked the distinguished aerial expert Dr L. J. Chu to conduct a theoretical study of the electrical behaviour of the dipoles. Later Terman wrote:

> To my knowledge this was the first theoretical study of Window [as it was known in Britain] - the British work I had seen was all experimental. Chu investigated the scattering cross section as a function of frequency for rectangular sheets with random orientations, making calculations for varying ratios of width to height. Also, because Salisbury had been thinking in terms of other shapes, Chu likewise developed formulas for the scattering cross sections of cylinders, ellipsoids with high degrees of eccentricity, and various other geometrical shapes. Chu completed his work in a few months and wrote a report giving formulas, sample results and curves.
>
> The Chu report was filed in a safe because that was all we could do with it, but it was not forgotten. After the passage of some months I concluded that although Window was still super top secret, the war was developing and that one of these days someone was going to start using it. When this happened, the United States needed to be ready to participate. Accordingly I gave the astronomer Fred Whipple, one of RRL's new recruits, the job of looking over Chu's report with particular reference to practical applications. After studying Chu's results, Whipple came up with an observation of great practical significance. This was that it was implicit in Chu's mathematics that the scattering cross section over a wide band of frequencies that could

> be obtained from a pound of aluminum foil would be greatest if the foil was in the form of resonant dipoles; and that Chu's theoretical formulas could be arranged to demonstrate the unexpected conclusion that even far off resonance the narrower the dipole the greater the scattering cross section would be for one pound of foil. (7)

Today Whipple's conclusion, that a given weight of metal foil would function most effectively if it was cut into thin lengths resonant with the radar to be interfered with, is so obvious that it hardly warrants comment; but, like Cockburn's discovery that random noise was the most effective way of modulating a jamming transmitter, at the time the discovery represented a major step forward. For the moment Terman could not conduct practical tests to confirm the validity of Whipple's theory, because of the security clampdown in the USA. Details of the discovery were passed to the Telecommunications Research Establishment in England, however, and led to immediate tests with the thin resonant strips there. These demonstrated that Whipple's conclusions were correct, and the Royal Air Force placed a large order for strips cut to half the wavelength of the German Wuerzburg radar; as they left the factories the strips were stockpiled, ready for the time permission was given to use the countermeasure against the enemy.

Most of the work on jammers at RRL during the early months of 1943 was devoted to airborne equipment for the Army Air Forces. There was one notable exception, however. At this time design work began, in conjunction with the Naval Research Laboratory, on a 150 watt shipborne jammer using a magnetron as power source, to cover the frequency band 350 to 800 MHz. This device would later go into production at General Electric, designated the TDY. (8)

III

Clark Cahill's radio counter-countermeasures team at RRL was charged with the task of reducing the vulnerability of the US radars to possible enemy jamming, and training the operators to be able to work through jamming if possible. Several radars were examined from this aspect including the naval FD equipment, a shipborne surface-to-surface gunlaying set operating on 700 MHz; Stanley Kaisel was one of the RRL engineers involved with this project:

> We found there was a lot a good operator could do to improve his ability to see through jamming. While this work was in progress I visited the US Navy headquarters at Casco Bay, Maine, which controlled the Atlantic fleet's cruisers and destroyers. Chatting to their radar people, I found they knew nothing about jamming or operating techniques to counter it. I returned to RRL and said to Dr Terman "This is terrible, what those guys need is training. We can reduce their vulnerability tremendously if we get a training program going." And in typical Terman fashion he replied "Do it !" That was his style, he was very good at turning people loose. We found the Navy had produced some simulators for training operators on the FD radar, so we had one delivered to RRL and I began work on modifications to it to show what the various forms of electronic jamming would look like. About half way through I was transferred to another job; Don Scheuch completed the modification work and I understand it was well received by the Navy.
>
> It was at about this time that the air defence radars around Boston experienced their first jamming. Once a week there would be a night exercise and one or more aircraft would fly past the defence radars on Blue Hill; and from the roof of RRL, about 10 miles away, we would watch the radar-directed searchlights tracking the planes. One day I thought: "I wonder how they will cope with a little jamming?" Well, somehow a jammer got itself tuned to the right frequency, a 100 watt amplifier was connected up, an antenna came to be pointing in the right direction and somebody must accidentally have flipped the switch. From then on the effect was fascinating. The searchlight ceased tracking the aircraft, wandered around for a bit, then switched off. When the radar signals ceased we could visualize

> the guys frantically pulling boxes out of the racks to try to discover what had gone wrong with their radar! The next day I confessed to Clark Cahill what had happened and he mentioned it to Terman; back came the word: "Please, don't do that again!" But I am pretty sure Dr Terman got quite a kick out of it all, and it would have strengthened his hand when he tried to sell the services on the need for anti-jamming training. (9)

IV

Early in 1943 the first RRL personnel arrived in England to join the staff at the Telecommunications Research Establishment (which by then had moved to Malvern in the west of England). Their arrival did much to strengthen the bonds between the two organizations, though the atmosphere at Malvern was quite different from that of inexperienced enthusiasm at Harvard as Dr John Dyer explained:

> I was greatly impressed by what I saw. They had a lot of tremendous people there with whom I got on famously - and still do. But the first thing that struck me when I arrived there was how tired and drawn they all were. They had been hard at it working seven days a week with scarcely a break for nearly two years, and they were simply worn out. Nerves became frayed and sometimes people got very tense. Bob Cockburn headed the British countermeasures development operation, in House 7 at the TRE. I was in his office one day with several of his group, when he and Martin Ryle [later Sir Martin Ryle, joint winner of the Nobel Prize for Physics in 1974] started to go at each other verbally; there was some really violent language. They stopped short, but only just, of having a go at eachother physically. Suddenly Cockburn turned to me and said "Dyer, am I not right?" Of course, there was only one answer I could give so I said "No!" That was not the answer Cockburn had expected, but it was the only one I was going to give whether he was right or wrong. That broke the tension and everyone burst out laughing. (10)

The RRL engineers were integrated into the British research teams, and when they returned to the US after a few months were able to take back many useful lessons.

V

So far the countermeasures equipments designed at the RRL had yet to exert any influence on military operations. But at sea the DAQ high frequency direction finder, developed by Maurice Deloraine and Henri Busignies at the ITT laboratories under the auspices of the Naval Research Laboratory, was beginning to have a considerable effect. The German 'Wolf Pack' tactics depended for their success on a shadowing U-boat being able to make and hold contact with one of the Allied convoys; from there the U-boat sent broadcasts at regular intervals to the German Navy headquarters in France, giving the convoy's position, heading and speed. Acting on this information the headquarters sent orders to the remainder of the U-boats in the pack to bring them together ahead of the convoy, in readiness to launch a concerted attack. From the Allied point of view, therefore, it was vitally important to find the shadowing U-boat and sink it or force it to lose contact. Huffduff, as the high frequency direction finders became known, gave a bearing on the shadowing U-boat when it transmitted the contact report; and the cross of two or more such bearings from different escorts positioned around the convoy gave the U-boat's position. In the official account History of United States Naval Operations in World War II the reader will find numerous endorsements of the effectiveness of this device (11). Typical of such reports is that from Captain Short USN, commanding the 6th Support Group comprising the escort carrier USS Bogue and the destroyers Belknap, Green, Osmond, Ingram and George E Badger. The Group was operating to cover the westbound trans-Atlantic convoy ON 184 during the latter part of May 1943; afterwards Short noted:

> The HF/DF equipment proved invaluable. On the morning of May 22 this equipment was used to home one of the TBF's [Avenger anti-submarine aircraft]. At 10.51 an HF/DF bearing was obtained on a submarine, but before this bearing could be transmitted a TBF on patrol had already attacked the submarine [U-305, which suffered damage]. In the afternoon, an HF/DF bearing was directly responsible for the attack on the submarine which surrendered [U-596, which was so seriously damaged that she foundered immediately after her crew abandoned her]. (12)

VI

During the first five months of 1943 the US radio countermeasures effort continued to make significant advances. The initial batches of RRL-designed jammers left the production lines and at sea the NRL-sponsored high frequency direction finders were adding to the effectiveness of Allied convoy escorts in their efforts to counter the German U-boats.

In this same period there was a major change in the American and British war strategies: their forces were now moving resolutely from the defensive over to the offensive in the European and Pacific theatres of operations. Radio countermeasures, predominantly a weapon to support the offence rather than the defence, were about to become more important than ever.

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CHAPTER 6 MEDITERRANEAN INTERLUDE

The success of the Ferret B-24 missions in the Aleutians demonstrated the value of this type of aircraft, and led to a requirement for others to be converted for use elsewhere. Ferrets III, IV and V, all B-17's, were allocated to the Mediterranean theatre where they were required to establish the layout of the German radar chain as part of the preparations for the invasion of Sicily (1) planned to open in July 1943 (Ferret II was to remain in the USA as a pattern aircraft).

Conversion work on Ferret III was completed in mid-April 1943. The suite of receivers fitted to the B-17 included a Hallicrafters S.27 with panoramic adaptor, an SCR-587 and an APR-3 wide-band receiver. In addition the B-17 carried directional aerials on each side of the fuselage to enable it to home on the source of any radar signals it found. The homing system was wired to give indications similar to a radio range: the pilot heard a series of morse letter A's in his earphones when he needed to turn right for the transmitter, N's when he needed to turn left, and a steady note when the aircraft was heading directly towards or away from the transmitter. (2)

With Lieutenant H. Millen in charge of the detachment Ferret III set out from Morrison Field, Florida, on 22 April 1943. Staging through Puerto Rico, Trinidad, Natal, Ascension Island, Dakar and Marrakech the B-17 arrived at Maison Blanche airfield near Algiers on 7 May. From there it moved to the nearby airfield at Blida which was to be its operational base for the initial operations. Sinclair and the two countermeasures officers on the B-17, 2nd Lieutenants Roger Ihle and Mathew Slavin, immediately made contact with their opposite numbers on No 192 Squadron of the Royal Air Force, whose converted Wellington bombers also operated in the Elint role. As a result of these discussions the American operators decided to modify their Ferret. On 11 May Sinclair noted in his diary:

> Lts Ihle and Slavin, in the light of their visit to the 192 Squadron Wellingtons, confirmed my previous opinion that we should mount the CRO [cathode-ray oscilloscope] and an audio oscillator to supplement, if not supplant, the ARL [Aircraft Radio Lab] pulse analyzer. It was also fairly obvious that, for radar search, the panoramic attachment to the S.27 was not particularly useful. It was therefore agreed that the [X]ARD, which is not operating properly, and if necessary the panoramic attachment, would be removed to make way for the CRO and audio oscillator sent along as test instruments. It was also agreed that, since several Freyas might be looking at us at once, the Zero Catcher [APR-3 wide band receiver] was not suitable for search equipment and the A-N directional antennas should be adapted to the S.27. The Zero Catcher, on the other hand, should serve as an excellent tail-warning device and it was agreed that it should be mounted in the tail. (3)

On 18 May the B-17 made its first operational test of the revised equipment layout. The Ferret took off from Blida, flew parallel to the north African coast and landed at Sidi Ahmed near Bizerte in Tunisia. During the flight Sinclair switched on the receivers and picked up signals from Freya radars on 122.5, 125.4 and 129.1 MHz, respectively identified as coming from Trapani and Marsala in Sicily, and from Sardinia. (4)

During the early morning darkness on the 19th the B-17 took off from Sidi Ahmed for a second operational test of its receivers, a flight which provided considerable excitement for the crew. Sinclair recalled:

> We went out and were stooging around getting all kinds of signals. I was listening to the low frequency receiver, mostly to Freyas. Slavin was using the other receiver when suddenly he got signals on 480 MHz. Now, 490 MHz was the German AI [airborne interception radar] band and I figured that was close enough. I said "Gi'me those phones!", stuck them on, and sure enough there were the signals obviously getting louder. I said "We've got a German night fighter on our tail!" (5)

Directed by the navigator, the B-17 performed a series of evasive manoeuvres in the darkness while the countermeasures operators tried to keep track of the movements of the other aircraft from its radar signals.

> From the directional antennas we could get an idea of whether he was to the right or the left of us. We were plugging in one, plugging in the other and could tell he was coming in from the right, coming in from the left. The radar signals were getting louder the whole time. I was standing in the radio room at this time, holding on one of the bars looking out of the window and I saw this airplane come up from behind us. And our tail gunner opened fire at him. The guy peeled off to the left and went down. He didn't come back, but on the other hand I didn't think we had hit him. We went down into a bank of cloud and began to breath a little easier.
>
> As we headed back to Blida I said "That may have been a Junkers 88, which the Germans are using as night fighters. But it might have been a British Beaufighter - they look very much alike. I think that when we get back we had better be quiet about all of this and put out a few feelers to find out what happened." After we landed we got a message from a Royal Air Force guy who had been flying a Beaufighter. He said "If you guys want to keep on living, you'd better learn to shoot straight!" He had come up behind us with his finger on the trigger of his four 20 mm cannon, recognized the B-17 outline and decided we were OK. And as he peeled off to the left our tail gunner had opened fire at him.
>
> Now the question was "How was it that we thought it was a German AI on 480 MHz, when it was really a British AI on 190 MHz?" That was where the God-damned harmonic came in, he was putting out such a powerful signal that we were getting an indication at 480 MHz on the dial. So before we made any further flights I designed a high-pass filter to take out anything over the band of frequencies we were looking at. (6)

Unless the operator was careful to cross-check his readings early superheterodyne intercept receivers like the SCR-587 were liable to tune to harmonic signals, indicating radar transmissions on a frequency higher than was the case. The flight on 19 May was one of the first instances of this to come to light during a search in the combat zone - usually there was no collateral evidence to indicate that the operator had been mistaken, and reports of harmonic signals were taken at their face value. The problem of harmonic signals, suggesting short-wavelength enemy radars which did not in fact exist, haunted World War II Elint operations.

On the night of 24 May the Ferret B-17 flew a third operational test from Blida, which took it almost up to the coast of Sicily. On this occasion signals from five Freya stations were picked up. The aircraft returned to Blida with three engines throwing oil, excessive fuel consumption, and one of the gun turrets not working. These faults would keep the bomber on the ground for several days. (7)

Initially nothing was easy for those trying to keep the B-17 Ferret flying. The detachment had no official designation and, to receive mail, the unit named itself the GR (General Reconnaissance) Squadron. Lacking an official table of organization and equipment to enable them to draw supplies in the normal way, the airmen kept going on items begged, borrowed or stolen from other American and British units around Blida.

One lesson from the early flights was that the homing aerial system fitted to the B-17 was not really suitable for operational Elint work. Sinclair recalled:

> When I got to north Africa I found it was fine in theory but a lousy operational system. You had to be flying towards the radar to get a bearing on it, and there was nothing more guaranteed to provoke an enemy reaction than to home in on their sets. I found that the antennas did not give a simple pattern. There were crevasses in the pattern and it was possible to fly at right angles to the source and at some point the signal would disappear and then come back in again. And at that point, if we knew where we were, we could get a bearing on the source. (8)

Using a VHF transmitter set up on the ground near the airfield at Blida, Sinclair and the two countermeasures operators calibrated the homing aerial system of the B-17 so that they could take accurate bearings on the transmissions as they flew past the source.

On 6 June the B-17 Ferret was ready to fly again, and when he switched on the receivers during the test flight Sinclair experienced the anomalous propagation of radar signals common in the Mediterranean area. He noted in his diary:

> In the afternoon flight we went out to sea off Blida to test the guns, which were now OK. The 125.2 Mc Freya, which has been logged so frequently, was heard at 1,000 feet (!) . . . The distance to Sardinia, where it is probably located, is over 300 miles.' (9)

The B-17 flew a further mission on the night of 8/9 June, to a point off the coast of Sicily. Then on the night of 14/15 the Ferret carried out its most ambitious mission so far, with a flight around Sardinia during which Ihle and Slavin logged numerous signals from enemy radars.

At the beginning of July 1943 the Ferret unit in north Africa underwent fundamental changes. Two more B-17's, Ferrets IV and V, arrived in the theatre bringing Lieutenant Colonel George Haller from the Aircraft Radio Laboratory and Richard Raymond from RRL as technical advisors. Don Sinclair returned to the USA. At the same time the unofficially named 'GR Squadron' was officially designated the 16th Reconnaissance Squadron (Heavy) Special, and soon afterwards Major Norman McGowan arrived to take command. With the receipt of an official table of organization and equipment, life on the unit became a lot easier. (10)

II

As part of the final preparations for the invasion of Sicily, Operation HUSKY, jamming equipment was moved up to the jumping-off ports and airfields. Several US Navy ships were fitted with the APQ-2 Rug jammer now available in small numbers; Royal Navy warships were fitted with the equivalent British Type 91 jammer. In each case the target of the jamming was the German Seetakt coastal search and gunnery control radar, which operated on frequencies in the 370 MHz band and was sited along the enemy coast in large numbers. (11)

To cover the night approach by Allied transport aircraft and gliders carrying airborne troops, eighteen Halifax and Wellington bombers of Nos 420, 424 and 425 Squadrons of the Royal Canadian Air Force, fitted with British Mandrel jammers, were to put up a screen of jamming to blot out the Freya and Wassermann early warning radars in the area. At the same time thirty-five USAAF B-17's, each fitted with an APT-3 Mandrel to jam Freya and an APT-2 Carpet to jam Wuerzburg, were to patrol off the coast to protect the force against radar-laid anti-aircraft fire. (12)

That was the plan, but due to an administrative hitch parts of it would not be fulfilled. In the USA the B-17's were fitted with the Mandrel and Carpet jammers under conditions of great secrecy, then flown to the base air depot in North Africa where the new crews assigned to the 16th Reconnaissance Squadron were to pick them up. Richard Raymond described what happened next:

> When the modified B-17's arrived at the depot in North Africa they were checked against the official manual; where there were listed items of equipment missing the depot staff would fit them, where there were items fitted which were not in the manual they were taken out. The jammers, being highly secret items, were not listed in the manual so they and their cabling were ripped out, and the B-17's were carefully demodified into normal bomber aircraft! When we discovered what had happened there was a dash to the depot to rescue the aircraft, but on this occasion the depot people had worked very fast and only four of the B-17's had not entered the demodification programme. (13)

The four B-17's which survived as jamming aircraft were whisked to Blida, the emaciated remnant of what should have been an important element in the countermeasures support plan.

The invasion of Sicily took place on the night of 9-10 July and the four B-17's fitted with jammers gave what support they could. While the jamming was in progress, Richard Raymond and George

Haller flew in one of the Ferret B-17's to monitor its effect; Raymond continued:

> We cruised up and down to the west of the island listening to the enemy radars and trying to discover whether the jamming was having any effect. From what we heard, nothing very important seemed to be happening. We remained in the area until midnight, then turned back to Blida. Unknown to us, however, the strong westerly winds that gave a lot of people trouble that night had blown us some way from our intended position. In fact we crossed the coast of Africa near the port of Bone, 130 miles to the east of where we should have, and "friendly" warships in the harbour indicated their displeasure with a barrage of anti-aircraft shells bursting around us. We changed altitude, airspeed and direction simultaneously, withdrew from the area, re-fixed our position and then headed back to Blida. (14)

The jamming from the four B-17's, combined with that of the warships carrying APQ-2 Rug, marked the first use of deliberate active countermeasures in combat by US forces. No proper analysis was ever conducted by the Allies of the effect of the jamming during Operation HUSKY, nor has the author been able to find any reference to it in German records. So we shall probably never know with certainty how successful - or unsuccessful - that jamming was.

III

Too late for the invasion of Sicily, the APT-2 Carpets removed from the B-17 jamming aircraft were recovered and sent to the 97th Bomb Group for installation in that unit's B-17's (15). For the remainder of the year a steadily dwindling number of Carpets would be used for self-protection during normal bombing attacks, though apparently with little effect. We shall return to the Mediterranean theatre, but now attention must shift to the countermeasures story unfolding in England.

REFERENCES TO CHAPTER 6

1. D. Sinclair Diary.
2. D. Sinclair interview.
3. Sinclair Diary, op cit.
4. Ibid.
5. Sinclair int., op cit.
6. Ibid.
7. Sinclair Diary, op cit.
8. Sinclair int, op cit.
9. Sinclair Diary, op cit.
10. R. Raymond interview.
11. 'RAF Sigs Hist. Vol. VII', op cit, 224.
12. Ibid.
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15. 'RCM Sum. Tech. Rpt Div. 15', op cit, 279.

CHAPTER 7 THE PACE ACCELERATES

In order to discover whether German anti-aircraft gunners were using the Wuerzburg fire control radar when engaging bombers in clear skies, in the spring of 1943 the Operational Research Section of the US 8th Air Force in England arranged for a British radar warning receiver to be fitted into an operational B-17. During the bombing attacks on Wilhelmshafen on 15 May and St Nazaire on the 17th, the receiver proved conclusively that Wuerzburg was indeed being used to track bombers in clear skies when optical fire control was possible (given the choice, gunners preferred to use optical azimuth information and radar range information in their predictors; for a description of the World War II heavy anti-aircraft gun operations, see Appendix D). With the discovery that Wuerzburg was more important to daylight flak operations than had been thought, Headquarters 8th Air Force ordered sufficient Carpet jammers to run an operational test against the German fire control radar (1). Thanks to the foresight of James McRae at the headquarters Army Signal Corps, Delco had the jammer already in production.

Shortly afterwards the 8th Air Force made a fundamental change to bombing tactics, which would heighten the need for radar countermeasures. Until now accurate attacks had been possible only when there were clear skies and bombs could be aimed visually. As a result the continually changing weather pattern over north-western Europe imposed severe constraints on the effectiveness of the daylight attacks. Forecasts of cloud over planned targets caused the frequent cancellation of missions; or, worse, bomber formations fought their way through the defences and suffered heavy losses, only to find their targets shrouded in cloud and accurate bombing impossible. The problem of attacking unseen targets was one long familiar to the British night bomber crews, however, and the Royal Air Force had recently put into service the H2S ground mapping radar and the Oboe ground controlled radar bombing system. In the summer of 1943 the 8th Air Force formed a Pathfinder Unit, the 482nd Bomb Group, with H2S- and Oboe-fitted B-17's and B-24's to lead attack formations. The US Pathfinders went into action for the first time on 27 September leading an attack on Emden, and quickly demonstrated their value (2). From now until the end of the war Pathfinder aircraft would fly at the head of most heavy bomber formations. If the raiders arrived to find clear skies at the target, the lead bombardiers would make visual bomb runs; if it was covered by cloud, the attack would be made using radar. Unless they resorted to barrage fire which was extremely wasteful in ammunition, the German gunners could engage bombers above cloud only with radar-laid fire; so if the fire control radars could be jammed the accuracy of the flak, and bomber losses, would both be reduced. If the initial operational test of Carpet was a success, it was clear the jammer would be needed in very large numbers.

Early in the autumn of 1943 sixty-eight APT-2 Carpets, many from the initial production batch which James McRae had ordered on his own initiative, were rushed to the air bases at Snetterton Heath and Knettishall in England and installed in the B-17's of the 96th and 388th Bomb Groups. On 8 October forty-two Carpet-fitted aircraft from the two Groups formed part of the 3rd Bomb Division attacking Bremen. The Carpets were pre-tuned with 500 KHz spacing, so that a 20-bomber combat-box formation radiated jamming spread evenly across the band 553 to 568 MHz covering the frequencies used by Wuerzburg at this time (3). The radio operator in each aircraft operated the jammer; he switched the Carpet to transmit as the formation entered the flak zone, and switched it off when they left it.

During the initial attacks on Germany in which Carpet was used, the two Bomb Groups whose aircraft were fitted with the jammer experienced significantly lower rates of loss than did the remaining Groups without it. That this should be so is surprising, in view of the fact that during the autumn of 1943 German fighters were shooting down considerably more US heavy bombers than were the anti-aircraft guns. During the first four attacks in which Carpet was used the heavy bomber losses, from all causes, were as follows (4):

Date	Target	Sorties	Lost	Percent Lost
Oct 8	Bremen	Carpet 42	1	2.4
		No Carpet 327	29	8.8
Oct 9	Gdynia	Carpet 52	4	7.7
		No Carpet 311	24	7.7
Oct 10	Munster	Carpet 40	2	5.0
		No Carpet 211	28	13.3
Oct 14	Schweinfurt	Carpet 52	7	13.5
		No Carpet 217	53	24.4
TOTALS		Carpet 186	14	7.5
		No Carpet 1066	134	12.6

The apparent lack of effect of Carpet during 9 October attack was because the two Bomb Groups equipped with the jammer made a second bomb run through the flak defences at the Gdynia, after their first had been disrupted by smokescreens on the ground (5). Without Carpet, their losses would undoubtedly have been much higher.

Clearly the jammer did provide useful protection against ground fire, and Headquarters 8th Air Force issued a requirement for sufficient Carpets to fit it to all heavy bombers. As the reader will see, however, several months would pass before this ambitious programme could be realized. In the mean time Carpet would have only a minimal effect on the overall number of heavy bombers lost: not enough of the jammers were available; and in the autumn of 1943 two-thirds of the bombers lost fell to attacks from enemy fighters, which Carpet could do nothing to hinder.

From the German point of view the initial introduction of Carpet into a small proportion of the US bomber force made little impact on the defences. In the autumn of 1943 the move was completely overshadowed by the large- scale use of Window (Chaff) by the Royal Air Force since the previous July, to cover night bombing attacks. The metal strips proved extremely effective against the Wuerzburg radars used for gun laying and night fighter control, and the Lichtenstein radars carried by the night fighters themselves. The Luftwaffe had to abandon its system of close control for night fighters, and until the defences could adjust to an entirely different system of loose-control for night fighting the Royal Air Force bombers enjoyed considerably lower loss rates. (6)

To reduce the vulnerability of Wuerzburg to Chaff, the Luftwaffe introduced two counter-countermeasures modifications under a crash programme: Wuerzlaus and Nuernburg. Wuerzlaus was a coherent-pulse doppler system, which enabled the operator to distinguish between the fast moving aircraft and the almost stationary cloud of Chaff. Nuernburg provided the operator with an audio facility, to hear through headphones any modulation on the radar echo signals: the echoes from an aircraft were modulated by the rotating propellers, those from the Chaff cloud were not. By November 1943 Wuerzlaus and Nuernburg were in large scale use. The two systems enabled radar operators to continue tracking aircraft flying through small quantities of Chaff, though both systems were liable to be swamped if infestation was heavy. (7)

On 20 December 1943 the 8th Air Force first used Chaff in action, dropped from B-17's and B-24's attacking Bremen. Aircraft from two Groups in each of the three Bomb Divisions (8) released bundles of Chaff Type CHA 3: 3,600 foil strips 10-in long, 1/20 of an inch wide with a 'V' crease down the middle to give rigidity, and just under 1/1000 of an inch thick; each bundle weighed 3 ounces. Initially Chaff was released by hand from the open waist gun positions, while the bomber formation passed through flak zones (9). The countermeasure proved effective in reducing losses, and its use was exetended to all bomb groups.

II

One problem faced on both sides of the Atlantic, now Chaff was being used in ever-increasing quantities, was how to produce it in the amounts needed. Matt Lebenbaum told the author how one of the engineering designers at RRL, Harold Elliott, and the mechanical model shop at the laboratory came up with a novel solution to the problem of Chaff cutting:

> The British had done a lot of work on Chaff, but they were having problems manufacturing it in the huge quantities required. Harold's Chaff-cutting machine was the neatest thing you ever saw. It was rather like a lawnmower with 20 blades, every second one of which was ground back slightly. The blades were rotated at 800 rpm by an electric motor and the first blade cut the foil, the second bent it along its length to give a 'V' shape for rigidity, the third cut, the fourth bent, and so on. With the blades rotating at 800 rpm the cutter produced 8,000 Chaff strips per minute. I think Harold Elliott deserves great credit for his little machine, without which we might never have produced enough Chaff to protect our bombers. (10)

The order to produce Harold Elliott's 'lawnmower' Chaff-cutter in quantity went to International Paper Box Company at Nashua, New Hampshire, a firm with considerable experience in making machines to produce cardboard boxes for the packing industry. Altogether 531 examples of the Chaff cutter were built (11). As soon as they were completed, the first 75 machines were flown to England at top priority. The consignment was considered so important that it was split between two aircraft, so that if even if one of the transports was lost part of the precious cargo would still get through. None of the initial batch were lost in transit, however, and Elliott's clever little machine would produce a large proportion of the Chaff used in Europe.

III

During September 1943 the Radio Research Laboratory reached a strength of 600 personnel of all grades of whom nearly 200 were engaged in research and engineering. The organization continued to expand, though not at its previous rate. (12)

A useful facility that became available to Division 15 at this time was the Army Air Forces countermeasures testing station set up at Auxiliary Field 9 (also known as Florosa Field), one of the satellite airfields near Eglin, Florida. Division 15 established a small laboratory at the airfield (13), where tests could be carried out using Army Air Forces aircraft. In the months that followed captured enemy radars, including the German Wuerzburg and Japanese Mark I Model I, were brought to Field 9 for tests to determine the effectiveness of the various types of jamming. (14)

Of the jammers under development at RRL in the autumn of 1943, the MPQ-1 Tuba designed by Dr Win Salisbury transcended all others both in the ambitiousness of its concept and its sheer physical size. This ground jamming installation comprised two 25 Kw transmitters using the Westinghouse-built Sloan-Marshal tube or Resonatron (a specially made high-power tetrode), as power source. The full installation was designed for carriage in six large trucks and two trailers, and included three 75 Kw diesel-electric generators to provide the power. The target of this powerhouse of jamming was the German Lichtenstein night fighter radar, operating on frequencies around 490 MHz. Beaming its output in a 30° arc eastwards over Europe, it was estimated that Tuba could put out sufficient power to cause 'white out' on Lichtenstein radar screens out to a distance of 200 miles from the jammer. The Royal Air Force placed an order for three Tubas to protect its night bombers. (15)

The prototype Tuba was set up at Harvard, with its aerial on the flat roof of the Hood Building. Salisbury arranged for a PBY Catalina flying-boat fitted with a receiver to fly through the area, to measure the strength of the jamming of various distances from the transmitter. Later Salisbury took the Tuba to the Army Air base at Bedford, Massachusetts, and set it up there. He found it would light a fluorescent tube a mile away from the transmitter. During a test against a 515 MHz ASB radar fitted to a B-17 flying over Philadelphia, a distance of more than 250 miles, Tuba prevented the radar operator seeing other aircraft flying nearby (16). Early in 1944 the first Tuba was ready to move to England.

Also at this time the APR-1 and APR-4 intercept receivers were placed in large scale production: the former was made by the Philco Corporation to an order from the Navy, the latter by the Crossley Radio Corporation for the Army Air Forces. But apart from this there were few differences between the two, both were based on the same receiver developed at RRL from the SCR-587. As with the earlier equipment there were plug-in tuning units to cover a wide spectrum, initially from 100 to 950 MHz, and as before the operator detected the radar by hearing its signals in his earphones. (17)

IV

In May 1943 Dr Karl Compton of the National Defense Research Committee headed a mission to England, to discuss setting up a laboratory there to facilitate the introduction of countermeasures equipment into US combat units in Europe. Air Commodore Edward Addison, the Director of Telecommunications at the British Air Ministry, promised every co-operation; he had commanded the Royal Air Force countermeasures unit No 80 Wing during the 'Battle of the Beams' and fully appreciated the value of such a facility to the Allied war effort. (18)

The new laboratory was to be part of Division 15. In June Dr Guy Suits penned a memorandum in which he set out its responsibilities:

> The prime consideration in the formation of this laboratory is the need of the US 8th Air Force for technical assistance in the development of applications of countermeasures. The laboratory, although working in close proximity to the British countermeasures group and taking advantage of their experience in this field, would primarily be serving the 8th Air Force as a using branch.
>
> One of the greatest needs for the Division 15 countermeasures programme in this country is operational information from which the laboratory developments can be given development priority commensurate with the needs of the various theatres. Up to the present time this type of information has been very inadequate, and it is certain that the formation of this laboratory in a war zone would be of immense value to the efficient operation of the Division 15 program here. (19)

In September 1943 the staff for the new laboratory began to assemble, in a hastily erected group of buildings alongside the Telecommunications Research Establishment at Malvern. Victor Fraenckel became Acting Director of the new organization; its full title was 'American-British Laboratory of Division 15', but invariably this was shortened to 'ABL-15'. Dr Cockburn remembers well the arrival of the Americans in force to set up their own organization. He told the author:

> We at TRE were up to our ears in work and had been for such a long time, doing everything on a shoestring. Then suddenly this enormous fresh unit came in - in a short time ABL-15 was as big as our effort - with everybody beaming and shining with enthusiasm. By that time we were worked into the ground, it was very noticeable. There was great fraternity between ABL-15 and my department, we borrowed equipment from each-other and that sort of thing. But from the start it was clear that it was a separate effort and they were working on different things for their armed forces. (20)

Maintaining close and frequent contact with RRL via a secure teletype link, ABL-15 soon began to make its presence felt. The laboratory detached engineers to assist fitting Carpet jammers into bombers. And there were requests from operational units for assistance with other matters. One of the first of these concerned the need for modifications to the SCR-522 VHF radios fitted to the US aircraft, to reduce the troublesome interference from German Freya radars. John Hollywood devised a series of simple changes which cured the problem except when the aircraft was in the immediate vicinity of the radar and both sets operated on the same frequency (the effect of SCR-522 on Freya was reduced when the latter's frequencies began to spread over a wider part of the spectrum). The Base Air Depot at Burtonwood in England incorporated the changes into all SCR-522's in the theatre, and eventually some 20,000 sets were modified for the 8th and 9th Air Forces. (21)

Another of the early projects undertaken by ABL-15 concerned the fitting of Hallicrafters S.27 receivers and magnetic wire recorders into a few bombers, to record German ground-to-air communications for analysis by the Intelligence service. Later the Hallicrafters receivers were replaced by captured German FuGe 16 aircraft VHF sets modified at the laboratory. (22)

V

Following the British use of Window (Chaff) on a large scale in July 1943, the Luftwaffe High Command permitted its bombers to use

'Dueppel' - the German code-name for this countermeasure. From the first week in August, German night bombers attacking targets in the Mediterranean theatre released Dueppel: strips of heavy metallized paper measuring 79.5 cms by 1.9 cms (31¼-in by ¾-in), intended to counter Allied anti-aircraft gunlaying, fighter control and night fighter radars in the 150 to 225 MHz band. (23)

Following one of these attacks the officer commanding the US Army 354th Coast Artillery Searchlight Battalion, part of the defenses of Bizerte in Tunisia, reported:

> During the air raid on Bizerte on the night of 5th September 1943, an SCR-268 crew detected enemy planes approaching the north side of the searchlight area. A target, assumed to be the leading plane, was illuminated at about 15,000 yards slant range. Upon being illuminated this plane turned back, and at the same time many stationary targets appeared in the oscilloscopes of the SCR-268's. These stationary targets were detected in all ranges out to 30,000 yards along the coast west of Bizerte, some at an altitude estimated at 6,000 feet. The operation of the SCR-268's along the coast was almost completely nullified by these stationary targets which appeared as echoes from aircraft.
>
> Targets that attempted entrance on the west side of the searchlight area were illuminated many times at slant ranges of about 15,000 yards, and upon being illuminated turned back and went out of searchlight range. The area west of the searchlight defence area was soon filled with the same "bouncing fixed echoes" from 15,000 to 25,000 yards, but when an echo from an airplane did emerge from this mass of interfering echoes, it was in most instances at a greater altitude. The result of this condition was that the radar and searchlight crews illuminated most of the targets entering from the west. There was a clear space in the oscilloscopes from the main pulse out to 15,000 yards in which to make the pick-up, and the operating crews soon noticed that the interfering echoes were weak when the antennae were elevated to approximately 45°.
>
> The SCR-268's located in the interior of the area and along the south side of the area experienced little or no interference from unusual strange echoes. These operators did very good work in illuminating the targets that did come within range. (24)

It can be seen that, in general, only those SCR-268's nearest the bombers' avenues of approach suffered seriously from Dueppel. The Beaufighter night fighters of the USAAF and the Royal Air Force took a steady toll of the attackers, in spite of the foil. Rarely did more than twenty bombers take part in any one attack, and with so few aircraft the Luftwaffe could not achieve densities in any way comparable with those put down by Allied heavy bomber forces.

VI

Since the US entry into the war, neither the Germans nor the Japanese had sprung any technical surprise which demanded an immediate radio countermeasures response from Division 15, the Aircraft Radio Laboratory or the Naval Research Laboratory. This pleasant state of affairs ended abruptly in the summer of 1943, when the Luftwaffe introduced into service two new and potentially devastating types of air-launched anti-shipping weapon: the Henschel 293 glider bomb and the Fritz-X guided bomb. Both missiles employed the Kehl-Strassburg system of radio command-to-line-of-sight guidance, using one of 18 channels in the band 48 to 50 MHz. After launch, the aircraft's bomb aimer directed the missile on to the target using a small joy-stick controller. (25)

The Henschel 293 was intended for use against merchant ships or unarmoured warships. It resembled a small aircraft with a 10-foot wingspan and carried a 1,100 pound warhead; after release from the parent aircraft, a rocket accelerated the missile to about 370 mph after which it coasted towards its target in a shallow dive. The Fritz-X guided bomb was intended for use against armoured warships and was released altitudes around 20,000 feet. The 3,100 pound weapon looked like an ordinary bomb, except that it had four fixed stabilizing fins mid-way along its body and moveable control surfaces fitted at the rear of the cruciform-shaped tail; it was unpowered, but fell under gravity to reach an impact velocity close to the speed of sound. (26)

The Henschel 293 was first used in action on 25 August 1943, during an attack on a Royal Navy anti-submarine group in the Bay of Biscay. One escort was sunk and another damaged. (27)

Fritz-X scored its first and greatest success on 9 September, as the main body of the Italian battle fleet was on its way from La Spezia to Malta to surrender to the Allies. Just off Sardinia twelve Dornier 217's of the IIIrd Gruppe of Bomber Geschwader 100 caught up with the fleeing warships. Of the twelve Fritz-X missiles dropped during the attack, two hit the battleship Roma which caught fire then blew up with heavy loss of life; her sister ship, the Italia, suffered a single hit but survived. Other missiles scored near misses on the warships. (28)

On that same day, 9 September 1943, American and British troops stormed ashore at Salerno in southern Italy and during the week that followed the missile-carrying Dorniers were heavily engaged in attacking shipping off the beachhead. Fritz-X's scored hits on the British battleship HMS Warspite and the cruisers USS Savannah and HMS Uganda, all of which suffered severe damage; the missiles also sank three smaller ships. (29)

Fortunately for the Allied warships, covering fighters were soon able to establish air superiority over the area around the landings and this curtailed the activities of the missile-carrying bombers. That was one answer to the problem. But another was obviously to build a jamming transmitter able to neutralize the Kehl-Strassburg radio guidance system. Bill Howe and Carl Miller at the Radio Division of the Naval Research Laboratory were amongst those drawn into the AAA1 priority project to devise a jamming system to counter the German missiles (AAA1, the highest priority rating, meant work had to continue round the clock until it was completed). Howe remembered:

> At the time we had no idea in which part of the frequency spectrum the missile guidance signals were being transmitted; so to cover all the probable bands we modified Navy versions of the Hallicrafters S.27 and S.36 receivers (respectively the RBK and RCX) for our purpose, which together covered the spectrum from 27 to 220 MHz. These receivers were modified into intercept devices by the addition of motor-tuning, a scope on which the output signals were displayed, and by reducing the selectivity of the IF stages so that they gave a broader band-pass and so enabled the operators to search the frequency spectrum more rapidly. During a period of about six weeks we hastily modified some 20 pairs of receivers in this way. They were fitted into warships and went to sea, that was the last I heard of them. (30)

It was easy enough to modify receivers to cover the required spread of frequencies but, as Carl Miller explained, the design of a suitable jamming transmitter proved more difficult:

> Building a transmitter to cover the required band was a bear, that is one of the most difficult frequency spreads to cover. In the end we managed it by dividing the coverage into a couple of bands. We built a series of experimental jammers, the XCJ, the XCK and the XCL, which solved the problems in different ways. We never had any time to test the jammers, however, because as each hand-built set was completed somebody from the fleet would come and grab it from the laboratory; it would be hastily fitted into one of the warships and off it would go to sea. We made about five of the jammers during the summer and early autumn of 1943. (31)

The first NRL-built anti-missile jammers and modified receivers were installed in the destroyers USS Davies and Jones at the Norfolk Navy Yard (32), and in October they set out for the Mediterranean. Both ships took part in the action on 26 November, when Major Rudolf Mons led twenty-one Heinkel 177 heavy bombers of IInd Gruppe of Bomber Geschwader 40, each aircraft carrying two glider bombs, against convoy KMF 26 off Algeria (33). The two US destroyers began jamming as the missiles came in, but the ships' countermeasures operators found it impossible to spot-jam all of the missiles simultaneously on different guidance channels, and several of the glider bombs were steered towards their targets. The attackers scored hits on the large troopship Rohna, which sank with heavy loss of life. (34)

By the autumn of 1943 the scale of Allied fighter cover for shipping in the Mediterranean was such that German bombers attempting attacks often incurred heavy losses. This was the main factor which prevented the guided missiles from achieving more successes, rather than the hastily improvised jammers; the jammers provided a useful 'last chance' defence when ships were under attack, however, and did much to raise the morale of those on the ships permitted to know of their existence.

VII

The final months of 1943 had seen a period of consolidation and general acceptance of radio countermeasures by US forces in the European theatres. Those responsible for directing the operations of strategic bomber units and warships were coming to realize that here was a new form of warfare the could not afford to neglect. In place of the previous indifference, RRL now had to meet priority demands for the equipments it had designed. The APT-2 Carpet jammer and the APR-1 and APR-4 receivers were in full production, and Chaff was being manufactured in large quantities. The status of radio countermeasures had risen considerably since the beginning of the year.

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CHAPTER 8 THRUST, PARRY, COUNTERTHRUST

By the beginning of 1944 the battle had opened in earnest between Carpet and Chaff, on the one side, and the German Wuerzburg fire control radar on the other. After the 8th Air Force first used Chaff in December 1943, consumption increased rapidly: in February 1944 the bombers dropped 40 tons, in March 125 tons, in April 260 tons and in May 355 tons (1). Due to distorting factors it is not possible to calculate with precision the effect this had on heavy bomber losses: during the same period the 8th Air Force increased the size of its raiding forces, they began penetrating deeper into Germany and the anti-aircraft gun defences increased in strength. There can be no doubt, however, that the decrease in the effectiveness of radar-laid anti-aircraft fire was considerable. Operating from bases in Italy the 15th Air Force began using Chaff on a large scale from March 1944, with similar results. (2)

In January 1944 the Aircraft Radio Laboratory at Wright Field sent representatives to England to question personnel at all levels on the use of Chaff. One of those interviewed was Lieutenant J. Dale of the 96th Bomb Group, a B-17 unit based at Snetterton Heath in Norfolk, who described the tactics used in the 3rd Bomb Division:

> Every plane in the Lead Combat Wing of the Division carries and dispenses Chaff. They fly at altitudes ranging from 23,000 feet and 27,000 feet. Each plane carried two cartons of Chaff containing a total of 144 packages. The dispensing procedure starts four minutes before the target is reached and continues until three minutes after leaving the target. The material is dispensed at the rate of about one package every four seconds. This lays down a Window lane of approximately 21 miles in length. No attempt is made to coordinate the dispensing operations between the various planes in the Combat Wing except in

> so far as the starting time is set by a signal from the Pathfinders when the Initial Point is reached. If the Division contains four Combat Wings the first and fourth Combat Wings carry Window; if less than four, the first Combat Wing only carries Window.
>
> In these missions dispensing operations are carried out by the radio operator. The window in the radio compartment of the plane has been removed and a chute of about 4 inches by 4 inches cross-section has been installed in the side of the ship in place of the window. The chute is inclined at 45 degrees to the fuselage surface of the side of the plane and extends somewhat through the surface in such a way as to form a cowling, which produces a strong air current from the inside to the outside of the plane. When a package of Chaff is inserted in the chute it is forced out rapidly by this air blast and opens soon after it leaves the chute. (3)

In contrast to the huge increases in the use of Chaff during the spring of 1944, Carpet had made little progress since the 8th Air Force first began using it the previous October. On 6 April the supply position was as follows (4):

1st Bomb Division (B-17's)	305th Group	43
	306th Group	48
2nd Bomb Division (B-24's)	44th Group	6
3rd Bomb Division (B-17's)	96th Group	39
	388th Group	35
Miscellaneous		31
Total in use		202
Lost in operations (6 Oct '43 to Mar '44)		101
Total Delivered		303

A further 210 Carpets had left the factory and been delivered to the service, but it was clear that when these arrived they would do no more than replace losses. The planned deluge of Carpets to the front-line units from the Delco production line was still far from reality.

Since the capture of the Wuerzburg radar by British paratroops in February 1942, the Signals Branch of the Luftwaffe had expected the Allied countermeasures offensive against this radar to begin with electronic jamming (5). Accordingly it had ordered the Telefunken company to develop modifications for Wuerzburg to enable it to operate on an extra band of frequencies and be able to shift rapidly within bands. The original Wuerzburg operating frequencies, designated the 'A band', ran from 553 to 566 MHz; the new frequencies, designated the 'B band', ran from 517 to 529 MHz. As part of the modification, code-named Wismar, the radar was fitted with a wide-band aerial to accommodate both bands. With practice a good crew could shift frequency within the band in use in less than one minute; changing from one band to the other required the services of a mechanic and took about four minutes. (6)

Immediately after the introduction of Carpet the Luftwaffe instituted the Wismar modification programme and by March 1944 work had been completed on a substantial proportion of the sets. Also at this time a new flak-control radar, the Mannheim, entered service with several detailed improvements over Wuerzburg. Both radars operated on the same frequencies, carried the same anti-jamming devices and were similarly susceptible to Allies countermeasures, however, so in this account they may be considered as one.

By the spring of 1944 the majority of Wuezburg and Mannheim radars carried the Wuerzlaus and Nurnburg modifications to give relief from Chaff. (Note: the German anti-jamming modifications are described in greater detail in Appendix E). In combat the operators soon discovered, however, that Wuerzlaus and Wismar were not compatible. When they shifted frequency using Wismar, Wuerzlaus had to be carefully re-adjusted and this took a considerable time. (8)

To keep track of the widening spread of the Wuerzburg frequencies a few B-17 Flying Fortresses of the 94th Bomb Group, based at Bury St Edmunds, were modified to act as monitoring aircraft in addition to their normal bombing role. Each of the aircraft carried additional crewman to operate the APR-4 receiver. ABL-15 engineers Matt Lebenbaum and Jerre Noe went to Bury St Edmunds to install the APR-4's and also a British radar intercept recording receiver, 'Bagfull', which required no attention in the air (9). In the months that followed the 94th Bomb Group monitoring aircraft, flying with their unit during normal attacks, would bring back much valuable information on the changing operating pattern of the German defences.

During the spring of 1944 a slow increase in the number of Carpets available to the 8th Air Force enabled a few other Bomb Groups to receive the device. Lieutenant Joe Wack, who had been kicking his heals since he graduated from the radio countermeasures course at Boca Raton in January, remembered:

> Towards the end of May 1944 a post in countermeasures was finally allocated to me in England, and I was sent to join the 448th Bomb Group of the 8th Air Force flying B-24's on strategic bombing missions from Seething near Norwich. When I first

arrived there the unit had no jammers but soon afterwards, immediately before the invasion of France, a team arrived and began fitting two APT-2 Carpets in the rear fuselage of each bomber. I was told to set up an RCM shop to maintain these. At first I had only an empty Nissen hut, but I soon got together a few radio mechanics and an experienced Staff Sergeant. We had to scrounge the desks, benches and ground equipment we needed, an activity in which my Staff Sergeant demonstrated considerable ingenuity.

Apart from keeping the Carpets serviceable, I was responsible for seeing that the jammers were pre-set to the correct frequencies. Each week we received from 8th Air Force Headquarters a histogram giving the frequencies - centred on about 560 MHz - on which the German Wuerzburg flak control radars were known to be operating. Each Carpet jammed over a bandwidth of only about 2 to 3 MHz, so those of the Group had to be set up on different frequencies to barrage jam the entire Wuerzburg band. Since the aircraft were not assigned until the morning of the mission, my section had a busy time adjusting the frequencies of the Carpets to ensure there was as complete and uniform a spread of jamming as possible over the threat frequencies.

In service Carpet proved to be pretty reliable. After each mission we would usually have to fix about one in ten, but generally the faults which developed were only minor ones and were soon cleared. Generally we had an adequate supply of spare parts. The only big problem was that we had hardly any technical manuals. Whenever we had the RCM installation people visit us to put sets into the aircraft, we would borrow their technical orders and make notes; but those guys were always careful to take their manuals with them when they left for the next base, where there was probably the same problem.

As the only RCM-qualified officer in the Group, it was my job to provide indoctrination in the subject for the rest of the aircrew. Carpet was new to everyone, but for several months the B-24's had been using Chaff against the Wuerzburgs. However the waist gunners who tossed it out of the aircraft had little idea of how it worked. When they were engaged by flak they had been told to dispense the foil as rapidly as possible. In some cases, I was told with more than a hint of pride, Chaff was hurled into the slipstream still in its boxes to increase the dropping rate! I gave a series of briefings on RCM to the aircrew, to teach people to use their equipment to best advantage. (10)

By the end of May less than one in ten of the heavy bombers of the 8th Air Force carried Carpet. To increase the effective spread of the jamming, ABL-15 developed a receiver to enable Carpet to be spot-tuned to the frequency of any Wuerzburg emitting nearby. J. Gregg Stephenson explained:

> To make the most of the limited number of Carpet jammers available, ABL-15 devised a simple "pointer" receiver to enable the operator to spot-tune his Carpet to the frequency of the Wuerzburg radar tracking his formation. We took a standard command receiver, of which there were plenty about, fitted a local oscillator and mixer designed and built at the ABL, and thus enabled it to pick up the Wuerzburg emissions. About 20 of these modified Command receivers were hand-built at the ABL and warmly welcomed by the 2nd Air Division, which was particularly short of Carpets for its B-24's. (11)

During May the first manually-tuned Carpets were fitted into B-24's of the 44th Bomb Group at Shipdham, and these opened the jamming attack on the lower frequency 'B Band' (517 - 529 MHz) now being used by Wuerzburg and Mannheim. In the months that followed other Bomb Groups had aircraft modified in this way.

These developments coincided with further changes in the tactics and operational methods of US bombers operating over Europe. Since the end of 1943 there had been considerable increases in the strength and effectiveness of US fighter escorts. Improved versions of the P-47 Thunderbolt and the P-51 Mustang now covered bomber formations deep into Germany, with the P-51's able to reach Berlin itself. The Luftwaffe fighter force suffered heavily from the escorts, and from the early summer only rarely were defending fighters able to attack the US bombers in force (12). At the same time the heavy bombers, exploiting to the full their new-found ability to penetrate to any target in Germany, encountered powerful flak defences more often than previously. The result was a sudden and dramatic reversal in the relative importance of German fighters and flak in terms of the numbers of heavy bombers they shot down, as the latter overtook the former (12):

	Lost to flak	Lost to fighters
Aug 1942 to Jan 1943	5	25
Jan 1943 to Jul 1943	166	500
Jul 1943 to Jan 1944	165	518
Jan 1944 to Jul 1944	847	637

These figures were compiled from debriefings of returned bomber crews and must be regarded as only an approximation: the causes to which heavy bombers fell were not always clear to crews in other aircraft who reported seeing them go down. Nevertheless, the table provides a useful overall impression of the causes to which bombers fell. The increase in the number of bombers shot down by flak did not stem from any increase in the effectiveness of individual flak batteries; it was simply that bombers were now attacking more difficult and heavily defended targets and they were doing it more often and in greater numbers than previously. Also, during the first half of 1944, the Luftwaffe had formed many new flak units and pulled back others from occupied Europe for the defence of the Reich. (13)

With the change in the main threat to the US heavy bombers during the early part of 1944, came a major change in their operating tactics. At the beginning of the year, when the German fighters posed the main threat and it was essential to concentrate the fire power from the bombers' own guns, the latter flew in squadron boxes of 18 aircraft with three such boxes stacked vertically to form an attack unit of 54 aircraft. Such formations were unwieldy and to hold them together required great skill from the pilots. The huge 54-aircraft formations were, moreover, ideal targets for the German anti-aircraft gunners since salvoes which missed one squadron box might well inflict damage on another. With flak the more serious danger in the spring of 1944, the size of the formations was reduced: the squadron boxes to 12 aircraft and the attack units to 36. (14)

As this was happening, the German moves to widen the frequency band of Wuerzburg began to take effect. Now with the 8th Air Force Headquarters at High Wycombe near London, Gene Fubini had the task of collating information brought back by US and British Ferret aircraft operating over occupied Europe, to determine the optimum frequency settings for Carpet. Each week Fubini's section sent to all operational heavy bomber units histograms showing the frequencies used by the German fire control radars against the numbers present in the various areas. (15)

In the autumn of 1943 a combat box formation of 20 aircraft, each carrying Carpet with the jammers' centre frequencies tuned 500 KHz apart, covered the entire Wuerzburg band of 553 to 568 MHz. In the summer of 1944 these tactics were no longer valid: the bombers flew in smaller formations and the frequency band of Wuerzburg now extended from 517 to 566 MHz. With about half the US heavy bomber attacks now being made through overcast using radar- bombing methods, many more Carpets were needed to counter the enemy radar-laid flak. But although this jammer was being produced in large numbers, more frustrating months would pass before it would be available to the front line units in the quantities required.

II

In February 1944 another major RRL-designed equipment was transported to England: Win Salisbury's tour de force, the 50 Kw Tuba ground jammer. Built into six huge lorries and two trailers, each encased in a water-tight crate for deck-loading on the freighter Maurice Sigmund, it weighed more than 170 tons and at the time was one of the largest single items of equipment ever to leave the port of Boston. (16)

After its arrival in England Salisbury set up the Tuba at Sizewell near Lowestoft in Suffolk, from where it was to beam its transmissions eastwards towards Holland, Belgium and Germany. Once he had it working Salisbury turned over his creation to the Royal Air Force.

Tuba was a magnificent technical achievement and it deserved to achieve great things. But circumstances were to conspire against it. For the jammer to be effective at its full range of 200 miles, line-of-sight considerations demanded that the victim radar - the 490 MHz Lichtenstein airborne intercept equipment - be at 25,000 feet or higher. But the Royal Air Force night bombers, and therefore the intercepting German night fighters, usually operated at altitudes around 20,000 feet; this limited the maximum effective range of the jammer to about 175 miles, somewhat short of the German border. Moreover the jamming could be effective only when the night fighter was pointing its nose, and therefore its radar, in the general direction of the jammer; this meant the bombers would receive protection only during their homeward flight. These two limitations were bad enough, but a further factor was to prevent Tuba from having any effect at all: before the jammer was ready for operation, Lichtenstein had all but passed out of service with Luftwaffe front-line units. The radar had proved extremely vulnerable to Chaff, and by the spring of 1944 it had largely been replaced by the new SN-2 radar operating on frequencies around 90 MHz (17). The low frequency of the new set meant it was not vulnerable to the Chaff then being dropped by the night bombers, nor to jamming from Tuba. Because SN-2 operated on similar frequencies to the Freya early warning sets it escaped detection by the Allied intelligence services for several months, and the Luftwaffe night fighter force enjoyed the unfettered use of the radar. The Royal Air Force operators switched on Tuba to support night attacks on numerous occasions in the summer and early autumn of 1944 (18). But a search of surviving German records revealed no mention that can be linked with the jammer and it is doubtful whether its thunderous crescendo was even noticed by the intended recipients.

III

In January 1944 Allied forces in the Mediterranean invaded Anzio south of Rome. To support their air attacks on the beachhead

German forces employed radar countermeasures. Luftwaffe personnel set up 'Karl' 500 watt ground jammers to counter Allied radars operating in the band 170 to 220 MHz. In addition German bombers carried 'Kettenhund', a self protection jammer to cover spot frequencies in the band 140 to 220 MHz (19); during operations with this jammer Luftwaffe tactics were similar to those of the USAAF with Carpet, with the tuning of jammers staggered throughout the attacking force to cover Allied fire control radars on a wide spread of frequencies. Used in conjunction with Dueppel, Karl and Kettenhund jamming proved effective against the American SCR-268 fire control radar.

To reduce the effect of the jamming, SCR-268's were hastily fitted with noise limiters and the receiver intermediate-frequency amplifiers were modified to reduce their bandwidth. More importantly, soon afterwards eight SCR-545 and twelve SCR-584 microwave fire control radars arrived at the beachhead to buttress the defences (20); operating on frequencies unaffected by the German electronic jamming and Dueppel, the new radars greatly increased the effectiveness of the Anzio gun defences.

Lest the reader imagine that when the German jamming was effective it was easy for bombers to attack shipping off the beachhead, however, it should be remembered that radar-laid anti-aircraft fire was only one of the hazards crews had to face. Oberfeldwebel Paul Balke was flight engineer on one of nine Dornier 217's of IInd

Gruppe of Kampfgeschwader 100 which set out carrying glider bombs to attack shipping off the invasion area at dusk on 16 February. The Dorniers left from Bergamo near Milan during the late afternoon and headed west over the sea intending to approach the target out of the setting sun. As the bombers passed Elba, however, enemy fighters were seen. The Dorniers hastily broke formation, dived to low altitude and headed for the relative safety of land. No fighter attack followed, but the raiders were forced to make their way to the target individually. As Balke's aircraft reached Anzio it was already getting dark; he later told the author:

> When we arrived the attack was already in progress. We did not see any other Dorniers, but from the ferocity of the flak it was obvious they were in the area. The ships put up a terrific barrage, as did the batteries on land; also some of the warships began laying smoke screens. We climbed to about 2,500 metres [8,000 feet] and circled the target, then picked out a ship and headed towards it. Hauptmann Schacke, the observer, released the left bomb at a range of 7 km [about 4½ miles], which meant the missile had a flight time of about 50 seconds. After launch we could see the red flare in the tail of the missile clearly as Schacke guided it towards the ship. From where I saw it, the flare seemed almost stationary; each time it moved slightly off the target, Schacke guided it back on again. As the range increased the flare gradually became fainter and fainter, then there was a white explosion as it struck the ship almost amidships.
>
> Once we no longer had to hold our flight path to guide the missile, we could evade that terrible flak. We circled the target once more, selected another ship, then ran in to attack. With a great deal of iron flying through the sky we released our second bomb and Schacke started to control it. But this time several ships started to concentrate their fire on us and there were tracer rounds streaking past from almost every direction. With the general confusion of the tracer flying about, and the smoke screens laid by the ships, we lost sight of the tracking flare. (21)

Left to its own devices the second glider bomb almost certainly crashed into the sea. Back on the ground at Bergamo the aircrews were surprised to find that all the Dorniers had been able to regain their base though one had flak damage. In spite of jamming on the missile guidance channels from the destroyers Davis and Jones, glider bombs hit and sank the 7,000 ton transport Elihu Yale and a tank landing craft (22). Such successes were few and far between for the German missile-carrying units by this stage of the war, however.

IV

At the beginning of 1944 Division 15 received a further major influx of skills when it took over the Airborne Instruments Laboratory at Mineola, Long Island. Dr Guy Suits told the author how he was able to acquire the laboratory as a going concern:

> This outfit had been part of Division 6 working on submarine detection methods, and had developed and seen into service the magnetic detector used with some success by the US Navy. But by the end of 1943 that work was complete and AIL had worked itself out of a job. Dr Donald Hare, in charge of the laboratory, was a very able guy and he had some very able people. And at that time Division 15 was still expanding and as always we were finding it hard to get enough of the right people. So at the beginning of 1944 the AIL and its entire staff of 180, about a quarter the size of RRL at that time, was incorporated into Division 15. (23)

By February 1944 the Allies had captured an intact guidance receiver from a Henschel 293 glider bomb, and its method of operation was clear (24). With the threat signals thus defined, the US Navy was able to be more specific about the type of jammer it required to counter the enemy guided missiles. At this time the RRL workshops were in producing a batch of fifty ARQ-8 communications jammers for the Army; this 30 watt jammer had an integrated receiver and could spot-jam channels in the band 25 to 100 MHz. Following representations from the Navy, the Army agreed to give up twenty of the jammers for conversion to the anti-missile role. The RRL hastily completed the work and rushed the jammers to Navy Yards at Boston and New York where they were installed into warships. (25)

Following its acquisition by Division 15 the Airborne Instrument Laboratory concentrated on developing methods of countering current and possible future enemy guided missile systems (26). At the time this seemed to be a major area of weakness in the Allied countermeasures programme: the Germans had already brought into action two types of radio guided missile and there was ample evidence that they were working on weapons of this type; there was no information on whether the Japanese were working on similar lines but it was prudent to assume they were.

AIL soon had a chance to prove its worth. In mid-April the Naval Research Laboratory placed a top-priority order for a high power jammer to counter the Kehl-Strassburg guidance system used by the German missiles in service. By concentrating almost all its resources on the project the laboratory was able to deliver the prototype of the new jammer to the NRL in just over two weeks. It is believed this is an all-time record for the design and production of a major countermeasures system. Designated the MAS, the device was a 250 watt jammer with a built-in receiver, able to cover spot frequencies in the band 41 to 51 MHz. By now it was known that the Kehl- Strassburg system operated in one of 18 crystal controlled channels in the band 48 to 50 MHz, with tone modulations on 1, 1.5, 8 and 12 KHz to convey the appropriate up, down, left or right command to the missile. To increase its effectiveness, the jamming from the MAS was square-wave-modulated at one of the tones used by the German transmitter. During tests the prototype MAS performed successfully and AIL received an order for a further forty-nine. (27)

V

The first five months of 1944 had seen a steady increase in the number of US countermeasures equipments deployed in Europe. During this period Division 15 was also heavily engaged in the preparations for the forthcoming invasion of northern France, and in seeing into service equipment for the B-29 force about to begin operating in the Far East. This work will be described in detail in the chapters which follow.

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CHAPTER 9 OPERATION OVERLORD

Whatever the success of the bombing attacks on Germany and occupied Europe, the Allied commanders knew ultimate victory could come only after ground forces landed successfully on the coast of north-western Europe and defeated the German army in battle. Should the landings fail, however, losses of Allied men and materials would almost certainly be so high as to preclude any further attempt for at least a year; and, relieved of the need to withhold a substantial army in the west, the German High Command could switch troops to the eastern front and possibly secure a decisive victory there. Clearly, whatever its outcome, the invasion of northern Europe would be a major turning point in the conflict.

Detailed planning for the invasion, code-named Operation OVERLORD, began late in 1943. Early on Allied staff officers chose the strip of Normandy coastline, bounded to the west by the Cherbourg Peninsula and the east by the estuary of the River Seine, as the main site for the landings. Soon after this decision came the first tentative discussions on the use of radio countermeasures to support the operation. The first expert in this field to become involved was Dr Robert Cockburn, head of the countermeasures section at the Telecommunications Research Establishment at Malvern. (1)

Cockburn and his team began work to prepare the countermeasures plan to support the invasion, but within a short time ABL-15 of the Radio Research Laboratory was closely involved also.

Security was tight and throughout the preparatory work nobody was allowed to know more about the invasion plan than was strictly necessary for his assigned task. As with most aspects of Operation OVERLORD there was close integration between the American and British efforts at all levels. Equipment and personnel were freely interchanged and each nation planned operations to assist the other's landings. Because of this, the account which follows will cover the whole Allied countermeasures plan in support of OVERLORD and not be restricted to just the American side of the operation.

When the landings began it was vitally important to delay the German reaction for as long as possible. The countermeasures operation supporting OVERLORD had, therefore, to achieve the following aims (2):

a) To prevent the enemy obtaining early warning of, and accurate plots on, approaching surface forces.
b) To prevent enemy coastal batteries from using radar-controlled gunfire against surface forces.
c) To support airborne operations by -
   i. Reducing and confusing the enemy's early warning system, thus delaying both the arrival of fighter amongst and alerting of the threatened dropping zones.
   ii. Interfering with enemy fighter control R/T, thus affecting both the movement of night fighters into the area of operations and the vectoring of intercepting fighters.
   iii. Producing diversionary threats and thereby dividing the enemy's available fighter effort.
d) To delay the movement of enemy reserve ground forces by producing threats of apparent assaults, both airborne and seaborne.

In order to reduce the problem of jamming and spoofing the German radar network along the coasts of France, Belgium and Holland to manageable proportions, the first priority was to knock out as many of the radar stations as possible. The target was a formidable one: as part of Hitler's West Wall there were no fewer than ninety-two radar sites on the northern shores of France and Belgium able to give warning of the approach of an Allied landing force (3). These stations were equipped with the entire menagerie of German ground radar systems: Mammut and Wassermann early warning radars, Freyas and Seetakts, Giant and small Wuerzburgs (for brief descriptions and technical details of these radars, see Appendix E). During the softening-up operations leading to OVERLORD, it was important that these give no hint of where the invasion was to take place. To keep the German High Command guessing, for every target attacked in the area of the intended invasion at least two were to be attacked in areas outside it. (4)

The success of air attacks on the German radar stations would depend on the accuracy of intelligence information on their locations. By the spring of 1944 Dr R.V. Jones's Scientific Intelligence department at the Air Ministry in London had built up a minutely detailed picture of the German radar network. But this picture had to be updated continually: radar sets, especially the highly mobile Freyas and Wuerzburgs, could be moved quickly and become operational within hours of their arrival at new sites. To assist in plotting the radars the Telcommunications Research Establishment produced a special ground direction finder code-named 'Ping Pong' which could determine the bearing of a radar transmitter to within a quarter of a degree. From widely separated points in the south of England three Ping Pongs took bearings on enemy radars along the north coast of France (5). After triangulation of the bearings thus found, photographic reconnaissance confirmed the exact positions of the German radar sites. Further help in locating the German radars came from the decoding of radio reports on the movements of Allied aircraft broadcast by the German air defence system. As part of a British operation code-named OCULIST, the Royal Air Force sent reconnaissance aircraft over occupied Europe flying carefully planned tracks and altitudes and photographing the ground beneath to provide an accurate record of their tracks. By picking up and decoding the German radio reports of the tracks of these aircraft, and back-plotting the distances and bearings given by the radar stations, intelligence officers were able to find the positions of several of the German stations. (6)

The radar stations were small pin-point targets, usually well protected by 20 mm and 37 mm anti-aircraft guns. The specialized task of destroying them was assigned to the Mosquito, Spitfire and Typhoon squadrons of the mainly-British 2nd Tactical Air Force. The anti-radar operations began on 16 March, when twelve Typhoons of No 198 Squadron set out for the Wassermann early warning radar stations near Ostend on the Belgian coast. During the initial attack four of the aircraft attacked the radar with rockets and cannon, while the other eight strafed flak emplacements surrounding the main target. As the fighter-bombers left the target the 130-foot high aerial tower was still upright, so during the late afternoon the fighter-bombers returned. More rockets hit the structure, but though battered the tower remained standing; at first it seemed that the radar had survived the attack (7). The Achilles' Heel of the Wassermann lay in the aerial rotating mechanism, however; the aerial was attached to a rotating sleeve which turned on a fixed vertical cylinder. Rocket damage to the sleeve prevented it rotating, and the design of the aerial was such that the tower could be lowered only if it faced in a certain direction. With the aerial tower now rigidly locked in the vertical position, German engineers had to dismantle the entire structure before they could begin repair work. The Ostend Wassermann would still be off the air in June when the Allied invasion began. (8)

The fixed-aerial Mammut also had a major weakness. The rear of the aerial frame was a mass of feeder cables which had to be carefully adjusted to give the correct beam shape; after adjustment, the radar had to be checked against a series of calibration flights by an aircraft flying a series of carefully set patterns. The feeder cables routed up the outside of the aerial were vulnerable even to small calibre machine-gun fire; and if they were hit the damaged feeders all had to be replaced and the tedious calibration process repeated. (9)

II

As the programme of attacks on the German radar sites began to take effect, the first specialist US radio countermeasures flying unit in England began forming: the 803rd Bombardment Squadron based at

Sculthorpe and belonging to the 8th Air Force, initially equipped with six B-17 Fortresses. In April Major C. Scott assumed command of the unit, which initially operated closely with No 100 Group of the Royal Air Force (an RAF Group is equivalent to a US Wing) also assigned to the countermeasures role. (10)

In May the 803rd Squadron transferred to a new base at Oulton in Norfolk. At the time of the move the unit possessed eight B-17s fitted with various combinations of Carpet and British Mandrel jammers (typically, an aircraft carried nine Carpets and four British Mandrels), a ninth B-17 was fitted out as a Ferret aircraft with SCR-587 and Hallicrafters S.27 receivers. The squadron was due to become operational early in June, in time for OVERLORD. (11)

III

By this stage of the war the Allied intelligence services were gaining such a wealth of information from de-crypted enemy signals that communications jamming was not permitted unless there were exceptional circumstances; but there was still a need to have such a capability in case the forthcoming land battle entered a critical phase where this type of jamming might swing the balance. During 1943 the RRL had designed a family of communications jammers to operate on the frequencies used by the German aircraft and tank radios. Two of these jammers, the airborne ART-3 Jackal and the ground MRT-1, went into limited production. (12)

The MRT-1, code-named 'Elephant Cigar', was another of Win Salisbury's super-high-power creations. This one operated in the 38 to 52 MHz band and radiated 50 Kw from a large directional aerial mounted on 105-foot high towers (13). One Elephant Cigar arrived in England in March 1944 and Royal Air Force technicians assembled it at a site near Brighton on the south coast. The work on the transmitter itself was completed in May, but that on the aerial had to wait until the last possible moment before the invasion - the aerial was to point towards Normandy, and if a German reconnaissance aircraft photographed it this could have betrayed the intended invasion area. (14)

IV

Also at this time work began in England to install countermeasures equipment into several warships and landing craft earmarked for OVERLORD. The task of fitting these to the US-assigned landing craft was the responsibility of the Special Communications Unit (RCM) at the US Naval Amphibious Supply Base at Exeter in Devon, under Lieutenant Commander Walter assisted by personnel from ABL-15. The crash programme to install the jammers greatly extended ABL-15 resources, however, and it immediately became clear that more personnel would be needed if they were to be fitted in time for the invasion. General Eisenhower sent an urgent message to General Marshall in Washington, requesting that further countermeasures experts from RRL be sent to England to assist with the invasion preparations. This drew an immediate response, and sixteen key members of the laboratory were rushed across the Atlantic to assist with the work. (15)

The initial plan was to fit the jammers into sixteen LCTA's (landing craft, tank, attack) and nine LCGL's (landing craft, gun, large). In each case the equipments specified - Carpet, Rug, American and British Mandrels - had been designed for installation in aircraft and there were problems putting them into landing craft. The following extract from the ABL-15 log (16) gives an idea of some of the difficulties, human and technical, facing those involved with this work:

> By May 24, all of the originally planned installations had been completed and checked, and six additional LCTA(5)s had been fitted with one RCM transmitter each. One American Mandrel, one British Mandrel, and four Rugs were included in this additional gear. It should be emphasized that the completion of these installations was possible only because of a great deal of hard work by the Navy technicians. Some of them worked 10 to 14 hours a day for more than three weeks, and none of them had a day of liberty in more than two months while the installations were in progress. Our experience in this business brought forcibly to our attention the very extensive amount of work that must ensue between the planning of the installation of X pieces of RCM gear on Y craft and the actual accomplishment of this goal. Particular credit is due to the Navy technicians who did the dirty work; they gave unstintingly of their time and energy on this job, and were a mighty tired crew when the last antenna was mounted and the last Onan bolted on the deck . . .
>
> Orders were sent to the captains of the LCGL and LCTA flotilla through Lt. Commander Walter to be transmitted to the skippers of the landing craft. These orders explained in detail how to turn the equipment on when the appointed hour came. Previously one of the officers had talked with each skipper, explained briefly the purpose of the equipment, and made sure that the skipper and the radioman or electrician knew how to turn on the RCM gear. Some of the skippers who really understood the nature of the equipment and its purpose were enthusiastic in desiring to have it. Others, who had a mistaken idea about its effect, were lukewarm or in a few cases openly antagonistic. The antagonism was felt by only a few C.O.s who somehow got the idea that enemy radar would DF on their jamm-

ing signals. We corrected every case of this nature that we found. The worst case was the skipper of an LCTA who waited until the techs had half completed an installation and then ordered everything taken off his craft.

A total of 16 LCTAs, 6 LCTA(5)s, and 9 LCGLs were finally fitted with RCM equipment. The following table shows the completed installations on US landing craft:

Set	LCTA	LCTA(5)	LCGL	TOTAL
Carpet	-	-	10	10
British Carpet	32	-	10	42
Mandrel	4	1	4	9
British Mandrel	-	1	-	1
Rug	-	4	10	14

The reader will recall that the British Carpets and Mandrels were similar in capability to the American sets of the same name, but had been designed independently. In addition to installing jamming transmitters to the landing craft, ABL-15 and US Navy personnel fitted the amphibious headquarters ship USS Ancon and the cruiser USS Tuscaloosa with a full range of listening receivers to cover the spectrum from 28 to 3,000 MHz (6,000 MHz in the case of the latter) (17); thus their operators couple monitor the spectrum, so that if the Germans introduced new types of radar or radio controlled weapons during operations against the invasion, the signals associated with these could be analyzed and countermeasures initiated with minimum delay.

Also at this time jammers were fitted into several of the Allied warships assigned to provide bombardment support for the invasion (18).

V

While US and British technicians were busy fitting proven equipment to the warships, the Telecommunications Research Laboratory was completing two new airborne homing devices specially for OVERLORD.

To secure the flanks of the seaborne invasion American and British troops were to carry out a large-scale parachute and glider assaults. Preceding these, pathfinder teams were to erect 'Eureka' radar transponder beacons to enable the main body of transport aircraft to locate their dropping zones. If the Germans reacted swiftly and sent aircraft to jam or spoof 'Eureka' they might seriously disrupt the airborne landings. To meet this possibility TRE engineers fitted four Mosquito night fighters with modified 'Lucero' equipment to enable them to home on aircraft carrying such jammers; only ten days elapsed between the formulation of the requirement and the initial proving flight by the first modified aircraft. (19)

Another interesting device which emerged from TRE at this time was code-named 'Abdullah', the first attempt to produce an airborne receiver for fighter-bombers to home on enemy ground radars. Tuned to the frequencies used by Wuerzburg, Abdullah was fitted to a few Typhoons used to lead formations during attacks on radar sites (20). Although the homer worked well enough during tests against a captured Wuerzburg in England, when used against German sets in northern France it was found that operators would switch off if they detected high speed contacts coming straight for them. Because of this, and the likelihood that a direct approach from such a homing would give operators warning of impending attack and time to alert the flak defences, the homer was judged technically successful but tactically unusable (21). Formation leaders proved able to find the radar sites using normal map-reading techniques, and used an oblique approach turning on to the target at the last moment to retain the element of surprise.

VI

While the systematic destruction of the German radar network in France and Belgium was in progress, and Allied engineers were hastily fitting countermeasures equipment into ships and aircraft for OVERLORD, Dr Cockburn and his team at the Telecommunications Research Establishment were putting the finishing touches to the most elaborate piece of electronic spoofery ever to support a military operation: the simulation on radar of two huge ghost 'fleets' to divert attention away from the main Allied landings. Obviously the simplest method of achieving such an aim would be to use large numbers of full-sized ships. But the invasion stretched shipping resources to the utmost and no large ships could be spared for this purpose. Cockburn worked out a method of producing a huge radar echo, similar to that from a large assembly of ships but without using any real ships. By dropping Rope - long lengths of metal foil - from aircraft flying carefully arranged tracks, he hoped to erect an enormous radar reflector covering an area sixteen by fourteen miles, a total of 224 square miles. (22)

The most important German coast-watching radar was the Seetakt operating in the 370 MHz band, and Cockburn planned his ghost 'fleet' spoof primarily to be effective against that system; he hoped it would also prove successful against other German radars. The beam width of Seetakt was 15°, so at a distance of ten miles the beam was over 2 miles wide. Allowing a margin for error, the plan called for Rope clouds within two miles of eachother along the frontage of the 'fleet' to produce a continuous 'blip' with no gaps on the Seetakt screen. The pulse width of the Seetakt was 3 micro-seconds, which meant that the set could not discriminate between objects less than 520 yards apart in range; so to get a continuous 'blip' on the radar in range, the Rope clouds had to be closer than that. The bombers releasing the Rope would be flying at 180 mph, three miles per minute; so if the crews dropped Rope at 12 bundles per minute this would result in one per 440 yards, sufficient for the purpose. (23)

Altogether, a full ghost 'fleet' operation required six to eight aircraft, split into two waves; the first wave would fly in line abreast with two miles between aircraft, and eight miles behind them would come the second wave in a similar formation. To simulate the advance of the 'fleet', the two waves of aircraft would fly a series of oblong 'race-track' patterns, each oblong measuring eight miles by two. Each orbit would take 7 minutes, and at the end of each the formation was to move forward one mile to give a rate of advance of the formation - and therefore the ghost 'fleet' - of 8 knots to make it look plausibly like an advancing assembly of ships. To add realism to the spoof other aircraft were to orbit nearby radiating Mandrel jamming on the German early warning radar frequencies; but in the areas of the ghost 'fleets' the aircraft would orbit in positions far enough from the German radars to enable their operators to discern the fake 'invasion fleet' through the blanket of jamming. (24)

During May 1944 Cockburn ran a ghost 'fleet' towards captured German Seetakt, Wuerzburg and Freya radars set up on cliffs overlooking the Firth of Forth; the spoof worked effectively against all of them. But the radar operators had all known they were seeing a simulated invasion fleet; the next stage was to test the spoof against operators who had not been told what to expect. Eight bombers flew a ghost 'fleet' against a British Type 11 radar, the nearest equivalent to the Giant Wuerzburg, situated at Flamborough Head on the Yorkshire coast. The unsuspecting operators reported the echoes on their screens as coming from a very large convoy indeed - far larger than any they had seen before. Now Cockburn and his team could be reasonably confident that the spoof would also work against German operators. (25)

Shortly before the invasion Cockburn obtained the use of a small additional force to assist with his spoofs: four high speed air-sea rescue launches and fourteen smaller naval launches not required for other tasks on the morning of the invasion. To add further realism to the ghost 'fleets' TRE engineers fitted the rescue launches with

'Moonshine' repeaters: devices similar to those used to support the US heavy bombers during their initial attacks in the summer of 1942, but now tuned to the 550 MHz Hohentwiel radar carried by German maritime patrol aircraft. Each launch was also to tow a float flying a 'Filbert': a 29-foot-long naval barrage balloon with a 9-foot diameter radar reflector inside the envelope to give a radar echo similar to that from a large ship. In addition to towing the floats, the fourteen small naval launches were to fly one 'Filbert' from their hulls. (26)

VII

By the evening of 5 June, when the vanguard of the invasion fleet set out from England, all but sixteen of the original ninety-two radar sites along the northern coasts of France and Belgium had been attacked from the air; most of their sets were now out of action, including all of the long range early warning Wassermann and Mammut radars (27). Now the 'softening up' phase of OVERLORD was complete, the jamming and spoofing phases could go ahead.

On the night preceding the invasion two ghost armadas 'set sail': The larger, with Rope dropped from eight Lancaster bombers of No 617 Squadron of the RAF, the Dam Busters, made for Le Havre - this was Operation TAXABLE; the smaller, flown by six Stirlings of No 218 Squadron, made for the Dunkirk, Calais and Boulogne area - this was Operation GLIMMER. Orbiting to the north of the real and ghost invasion fleets were four B-17's of the US 803rd Bombardment

Squadron on their first operational mission and sixteen Stirlings of the RAF No 199 Squadron; these aircraft put up a Mandrel screen to cover the various operations, with the jamming deliberately thin to the east to allow the German operators to observe the TAXABLE and GLIMMER spoofs. (28)

Beneath the orbitting aircraft and their falling clouds of Rope, the small flotilla of launches headed through the choppy sea with their ungainly 'Filbert' balloons trailing low over the water down-wind. Cockburn was full of praise for the Moonshine operators on the boats that night:

> The Moonshine operators came from an American Army signals unit. These men had arrived from Iceland too late to be brigaded into the main invasion, so they were given to us. They were absolutely first class. They hadn't seen any war, they were tickled pink at the idea of taking part and were keen as mustard. The launches ran in - can you imagine it, 6 knots in such a craft in a Force 6 sea? The Moonshine operators were seasick to a man but they operated their equipment magnificently. (29)

As the launches rumbled toward the French coast the Moonshine operators observed signals from German airborne radars on their cathode-ray tubes and returned them 'with interest'. (30)

When the two ghost 'fleets' arrived at their stop lines some ten miles off the coast of France, the launches anchored the floats with the 'Filbert' balloons then laid a smoke-screen and broadcast over loud-speakers recordings of the squeals, rattles and splashes germane to a large number of sea-going ships dropping anchor. Their deception task complete, the boats withdrew. (31)

While the TAXABLE and GLIMMER forces moved their laborious ways towards the coast of France, other mischief was afoot: twenty-nine Stirling and Halifax bombers of Nos 90, 138, 149 and 161 Squadrons of the RAF staged fake airborne invasions - code-named TITANIC - in the Caen and Cap d'Antifer areas. On their way to the 'dropping zones' the bombers released large quantities of Rope, to increase the apparent size of the force on enemy long range radars. In the simulated landing areas they unloaded large numbers of dummy paratroops fitted with special fireworks, which exploded to give off the crackles and bangs of a ground battle in progress; to add realism to this spoof, the bombers also dropped a few men of the British Special Air Service with orders to create diversions. (32)

To isolate the real dropping zones from marauding German night fighters, twenty-nine Lancaster and Flying Fortress bombers of the RAF Nos 101 and 214 Squadrons flew a communications jamming screen over eastern France. This was to ensure that enemy night fighters operating to the west of the jamming screen could not receive instructions from their ground control stations to the east. To increase the apparent size of this force on the German radar screens, and to give the enemy night fighters something to chase when they entered the area, these bombers too dropped large quantities of Rope. (33)

The spoofs were successful. The German fighter controllers fell into the trap and ordered night fighters to intercept the ghost 'bomber stream' over eastern France. But once the fighters were in the area of the communications jamming they could receive no further instructions from the ground, and wandered aimlessly among the clouds of Rope looking for targets until shortage of fuel forced them to return home. One of the RAF bombers involved in the operation was caught and shot down, but the crew survived (34). Meanwhile the huge armada of more than a thousand unarmed transport aircraft and gliders, laden with paratroops and their equipment, was able to deliver the airborne divisions to their drop zones and return to England without losing a single aircraft to night fighter attack.

More than two hundred warships and landing craft taking part in the main landing operation carried jamming transmitters, and all were switched on as the ships approached the beaches. A veritable powerhouse of jamming shimmered across the screens of those German coastal radars which had survived the bombing and strafing attacks during the previous weeks. There was nothing subtle about this, the final trick in the Allies' radio countermeasures repertoire. It blinded the defenders as cruelly and as effectively as pepper thrown in their eyes. Only one German radar was able to observe the approach of the real invasion fleet; and such was the general chaos in the area due to the various spoofs, it's warning went unheeded. (35)

The first indication that major forces were moving towards the coast of Normandy, to be believed by the German High Command, came at 2 am on the morning of 6 June when lookouts at observation posts on the eastern side of the Cherbourg Peninsula heard with their naked ears the rumble from the engines of the Allied ships. No conceivable radio countermeasures effort could have achieved more, for until then seaborne invaders' approach had been concealed.

Off the landing areas the jamming of the Seetakt fire control radars greatly reduced the accuracy of the return fire from the coastal gun batteries. Only one Allied warship, a destroyer, was lost to this cause though a few others suffered damage.

There is evidence that the German radar operators observed and reported the approach of the GLIMMER 'fleet'. A telephone message logged at 10.15 on the morning of D-day (36) at the forward echelon of Luftwaffe High Command (six hours after the end of the operation by which time Allied troops were ashore in strength) contains a clear reference to GLIMMER:

> On the night of 6 June the enemy carried out landings in the Seine Bay. Reports up to 0800 hours provide the following picture: at about 0300 hours a large number of enemy landing craft and escorts neared the coast of the Seine Bay between Caen and Carentan. From observations on the coast and air reconnaissance, it appears that some 200 ships were involved. Landings appear to have been successful near Carentan and near the mouth of the Vire. The number of landing craft involved has not been reported. Near Bernieres 33 landing craft have been reported, and 44 more near the mouth of the Orne (north of Caen). It is estimated that eighty large landing craft would be able to put ashore 3 to 4 divisions.

> During the early morning darkness (first light was at 0500 hours) artillery fire fell at the following places: Grandcamp, Colleville, Arromanches. There are no reports on the positions of the ships doing the firing. Between 0600 hours and 0700 hours coastal observers reported six large warships, including battleships, and approximately 20 destroyers at a position 10 sea miles west of Le Havre. Further reports on assemblies of ships: at 0645 hours to the north of Lesardrieux [west of St Malo], where it has been specifically reported that no landings have taken place up to now. According to reports from reconnaissance aircraft, ships were assembling during the morning off Dieppe and Le Treport. <u>The reports of ships assembling off Calais and Dunkirk at 0400 hours have not, so far, been confirmed.</u> [author's underlining].

The German commander in the area dispatched reconnaissance aircraft and patrol boats to scour the seas off the coast between Dunkirk and Boulogne for the suspected invasion force; but it took a disconcertingly long time to prove conclusively that the enemy was not in an area where he was is thought to be.

Operation TAXABLE, though probably correctly mounted, appears not to have been noticed by the defenders. Despite a careful search of German records the author has not been able to find any reports that can be linked to that spoof.

The rest of the story is well known. Once the Allied troops had established a beachhead in Normandy no power at Adolf Hitler's command could dislodge them. Some of the countermeasures prepared for OVERLORD were not needed. No new types of German radar or radio guided missile were brought into action against the invasion forces, so the comprehensive monitoring equipment on board the USS Ancon and Tuscaloosa revealed nothing important. Nor was there any German attempt to disrupt the airborne landings by jamming signals from the Eureka beacons marking the dropping zones, so the 'Lucero' Mosquitoes saw no action. As the ground battle developed the Allied fighter force maintained a powerful umbrella of protective patrols over the beachhead and it proved impossible for the Luftwaffe to mount co-ordinated attacks into the area. As a result the huge Elephant Cigar communications jammer at Brighton, though held ready throughout the operation to beam a cacophony of jamming on the German aircraft radio channels, remained silent. (37)

VIII

The success of the landings in Normandy completely overshadowed Operation DRAGOON, the landings on the south coast of France ten weeks later. Although smaller than OVERLORD, DRAGOON was large by any other standard: to support the landings by one US and two French Army Corps, 4 battleships, 9 aircraft carriers, 24 cruisers and 105 destroyers took part. These landings began with an airborne assault during the early morning darkness of 15 August supported by an all-British radio jamming and spoofing operation involving a Mandrel screen, dummy airborne landing and a ghost 'fleet' operation along similar lines to those during OVERLORD. But in this area the radar chain was far less dense than that in Normandy and the defending forces, their best units having already departed for the main battle in the north, were unable to pose any serious threat to the invasion force. (38)

IX

By producing confusion and preventing the German commanders from gaining an accurate appreciation of Allied movements, there can be no doubt that the radio countermeasures operations materially assisted the landings in northern and southern France and did much to reduce casualties. In terms of the losses they saved, the resources committed to countermeasures had been minimal. For the student of electronic warfare the operations in support of OVERLORD and DRAGOON provide an important object lesson on what can be achieved if a carefully planned programme of countermeasures is used to support a one-of-a-kind operation of the highest importance. For the run-of-the-mill bombing operations repeated day after day, week after week, such elaborate spoofery will soon be recognized by the enemy and in most cases will not be worth a large effort; but for once- or twice-in-a-war seaborne landing operations, where the risks are invariably high and the stakes large, such an effort will repay itself a hundred fold.

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CHAPTER 10 JAPANESE RADAR: THE PICTURE SHARPENS

While the countermeasures contest in the European theatre of operations approached its climax, events in the Pacific moved at a far more leisurely pace. Not only were the development and production of radar far slower in Japan than in Germany, but the vastly greater area of the Pacific war zone meant that the few available Japanese radars had to be spread far more thinly than were those in Europe. Following the capture of the Mark I Model 1 early warning radar on Guadalcanal at the opening of the Solomon Islands campaign in August 1942, and the subsequent discovery of similar radars on Kiska and Wake Island, new information on Japanese radars was slow to come in.

During the spring of 1943 Chief Petty Officer Jack Churchill and his Cast Mike 1 team continued to fly their intercept receivers with PBY Catalina squadrons resident in the south Pacific area. Between the beginning of 1943 and the middle of June the members of the team flew on numerous patrol missions - Churchill himself flew on 17 - but without detecting any enemy radar signals (1). Then on the night of 18 June, flying in a 'Black Cat' piloted by Lieutenant Harold Johnson of VP-54 near the Shortland Islands just south of Bougainville, Churchill picked up signals from an enemy set. But the Catalina carried no direction finder and it was impossible to pinpoint the location of the Japanese radar. During later missions other operators also picked up signals and confirmed the presence of an enemy radar in the area. (2)

The Cast Mike 1 team had no radar direction-finding equipment, nor was there a prospect of getting any in the immediate future. So Jack Churchill and his team improvised their own. Assisted by 'metal benders' of VP-54 they built a pair of Yagi homing aerials and fitted them on each side of the nose of a Catalina. These aerials were connected to an ASE radar receiver modified to accept signals on frequencies around 100 MHz, and the resultant output was displayed as left - right indications on the cathode ray tube of an ASE indicator unit (3). All in all it was a remarkable piece of improvisation, undertaken in the most primitive conditions on Guadal-canal.

Using the improvised direction finder, on the night of 8 Sept-ember Lieutenant Harold Johnson and his crew obtained three good bearings on the Japanese radar and established its position on Popor-ang Island south of Bougainville. Following this, a reconnaissance aircraft photographed the radar and the set was later attacked by fighter-bombers. (4)

II

Also in the summer of 1943 there was a resurgence of US countermeasures activity in the Aleutians, in preparation for an operation to re-take those islands seized by the Japanese the previous year. Initially it was felt that the two radars on Kiska, sited on a 525 foot hill and able to observe forces approaching the island from several sectors, might hinder such an invasion. To counter the radars it was decided to set up a ground jamming station on the 750 foot high plateau at Cape Bird on the US-held island of Amchitka, some 50 miles east of Kiska. The operation was code-named BEAVER. The 1st Signal Service Platoon (Special), with a strength of three officers and 40 enlisted men drawn from the Army and the Navy, arrived on the island after a hasty course of training at RRL to operate and maintain its equipment: an APT-3 Mandrel fitted with an AM-14 APT amplifier to boost its jamming power up to 140 watts, with directional aerials to beam the jamming at the Japanese radars. The ground jammers would be at the limit of the direct transmission path to Kiska but RRL experts had judged the operation to be technically feasible. (5)

As plans for the invasion of Kiska took shape, however, it was decided that the landings would take place on a part of the island in the blind sector of the Japanese radars. So the jamming from Amchitka could not screen the landings, though it might deceive the defenders by drawing their attention away from the real assault. While this was being considered the listening post on Amchitka logged signals on 300 MHz, thought to come from a new type of Japanese radar on Kiska. Immediately an APQ-2 Rug jammer was rushed to Amchitka to cover that part of the spectrum. (6)

In the event the BEAVER operation came to nothing. On 4 August, just over a week before the invasion was planned to begin, the Japanese blew up their radars on Kiska and abandoned the island under cover of fog. When US forces landed they found parts of two Mark I Model I radars, sets similar to that captured on Guadalcanal. (7)

Nothing was found of the 300 MHz radar and from Japanese records we know there was no such equipment. In retrospect it is clear that a spurious signal had triggered the scare, almost certainly a harmonic.

III

The installation of radar intercept equipment in warships was an obvious step once it was clear that the opposing side possessed radar, and it is interesting to note that Japanese warships began to carry such equipment some time before those of the US Navy. During the action between opposing cruiser and destroyer forces off Kolombangara Island in the Solomans on the night of July 12 1943, the Japanese destroyer Yukikaze was able to detect radar signals on 175 MHz from US ships (probably from their SA or SC air search radars) some two hours before the main engagement began (8). As a result, although the Allied warships carried superior radar, the Japanese destroyers were able to launch their torpedo attack first. In the ensuing action the destroyer USS Gwin was sunk and the cruisers Honolulu, St Louis and Leander damaged. The sole Japanese loss was the light cruiser Jintsu.

After the inconclusive action between opposing destroyers off Vella Lavella island in the Solomons on the night of August 17, three of the four Japanese destroyers involved were reported to be carrying radar intercept receivers. (9)

Shortly afterwards US Navy warships in the combat zone began carrying XARD and ARC-1 intercept receivers. One of the first to do so was the cruiser USS Montpelier, which took part in bombardments to support of landing operations on New Georgia in the Solomons in August; her operators were able to confirm the presence of Japanese early warning radars in the area. (10)

In September two US warships fitted with ARC-1 formed part of the escort for the carriers mounting air strikes on Tarawa in the Gilbert Islands. One of the ships carrying the receiver, the cruiser Minneapolis, afterwards reported:

> By keeping a careful watch on the Japanese radars on the small islands, it was possible for our force to evade many of them and at the worst know the moment when surprise was no longer effective because of radar detection. (11)

This operation provided some valuable lessons for the development of future Elint equipment and techniques. The report on the action recommended that in addition to intercept receivers, warships should carry equipment to measure the pulse repetition frequency and pulse width of radar signals so that operators could gain more information from the enemy transmissions. To assist operators to differentiate between friendly and enemy signals, the report asked that information be provided on the characteristics of friendly radar signals (this had not been available).

As the US Elint effort expanded, so did the number of reports of what we now know were spurious signals - though at the time it was difficult to discount the latter. By the late summer of 1943 US ships and aircraft had reported signals from possible Japanese radars on 34 occasions - but several of these were logged on frequencies between 300 and 700 MHz (12), a part of the spectrum where there were in fact no Japanese radars. These spurious signals appeared to indicate that the frequency spread of the Japanese sets was far greater than was the case. (2)

IV

Given the few intercept receivers available to the Allied forces in the Pacific theatre, the great distances involved and the scarcity of Japanese radars, it is hardly surprising that there were major gaps in the Allied intelligence picture of what the enemy were doing in this field. Throughout almost the whole of 1943 there was reliable information on only one type of Japanese radar, the Naval Mark I Model 1 early warning set. Even at the end of that period there was little evidence of enemy shipborne or airborne radars, or of radars for fire control; this, at a time when Japanese forces had deployed - albeit in small numbers - no fewer than three different types of ship-borne radar, an airborne radar for patrol aircraft and four different types of anti-aircraft gun and searchlight control radar (for a fuller account of the evolution of Japanese radar, see Appendix G).

Only near the close of 1943 did the first hard information on other types of Japanese radar begin to trickle in. On 2 November, following a low altitude attack by US bombers on shipping off Rabaul, New Britain, an aircraft returned with a photograph of a Nachi class cruiser showing a bedspring-type aerial on top of her mainmast (the aerial of a Mark II Model 1 radar) (13). At about the same time a radioman from the light cruiser Jintsu, captured after his ship was sunk in the action off Kolombangara Island, mentioned under interrogation that his ship had carried radar (14); he went on to state that all new Japanese cruisers carried the device. Another Japanese Navy prisoner, captured on New Georgia, repeated this assertion. (15)

Also during November 1943 a low-flying US reconnaissance aircraft photographed a previously unknown type of mobile radar (in fact a Navy Mark I Model 2) near Rabaul. (16)

In the autumn of 1943 the Navy Cast Mike 1 team of enlisted radiomen was disbanded, and in its place came teams of aircrew officers to carry out much the same task of installing intercept receivers into reconnaissance or bomber aircraft and operating the equipment in the air. One of those involved in the work was Lieutenant Lawrence Heron who, with another officer, received orders in

November 1943 to join Patrol Squadron VP-104 operating PB4Y Liberators out of Henderson Field, Guadalcanal. As in the case of earlier Navy aircraft involved in Elint work, Heron had to make his own installation to enable the ARC-1 receivers to be transferred from aircraft to aircraft; he recalled:

> We mounted our equipment on a couple of pieces of plywood, the sheets sawed so that they would fit through the hatches of the PB4Y. They could be carried into the airplane, fastened to a table and the power cables plugged in.
>
> Up to February 1944 I flew about twenty missions to such locations as Truk and Kapingamarangi [in the Caroline Islands] and several - which scared the Hell out of us - to Rabaul, New Britain, which was very heavily defended by the Japanese. (17)

V

Late in 1943 a new headquarters unit was formed in the South West Pacific theatre to co-ordinate Allied countermeasures activities in the area: Section 22 of General Headquarters. This inter-Allied organization, located at Brisbane in Australia, was commanded by Major General Spencer Akin of the US Army Signal Corps. Section 22 included members of the US Army Signal Corps, Army Air Forces, Marines and Navy, as well as British, Australian, New Zealand, and Dutch personnel. The headquarters was responsible for collecting information on enemy radar and radio systems, analyzing and disseminating intelligence and requisitioning and assigning countermeasures personnel and equipment. The Section was also responsible for analyzing Allied signals traffic for anything that might betray movements or intentions to the enemy, and training Allied radio and radar operators to recognize enemy jamming and where possible work through it. (18)

During the autumn of 1943 a further two B-24's, designated Ferrets VII and VIII, were prepared for operations in the Pacific theatre. One of those involved in the work was Lieutenant Frank Witry, a Boca Raton graduate assigned to the crew of Ferret VIII, who remembered:

> We were given an old B-24, it was the most pathetic looking airplane I had ever seen. When we first saw it at Eglin it was sitting on its tail with the nosewheel off the ground. It looked as if it had given up. We hauled it off to the sub-depot at Eglin and began work on it. We built a plywood compartment in the after end of the bomb bay to house two operators; the operators' seats were on the right side of the compartment and the equipment racks were on the left side. People from Wright Field and RRL assisted with the work.

The countermeasures suite for these B-24 Ferrets comprised SCR-587, Hallicrafters SX.28 and S.36 receivers, a panoramic adapter to measure pulse repetition frequency and a hand-built prototype recording receiver; there were omni-directional aerials and a motor-driven rotatable Yagi directional aerial system hand-built by RRL, which in flight was lowered beneath the fuselage of the aircraft. Late in 1943 the two new Ferrets set out for Australia where they were assigned to Section 22. (19)

By the end of 1943 Section 22 had begun to assemble a detailed picture of the enemy radar network in its area. The step by step collection of information on the Japanese radar site at Cape St George, on New Ireland in the Solomons, illustrates well the cumulative results of the Elint operations being mounted at this time; it also shows the limitations of the first-generation equipment used, which was liable to produce a spread of results: (20)

Date	Freq.	PRF	Remarks
Oct 11, 43	100 mc	800 cps	Heard 50 miles NE of Cape St George. Failed to track plane.
Oct 30, 43	101 mc	1000 cps	Heard 40 miles E Cape St George. Tracked plane.
Oct 31, 43	105 mc	1000 cps	Reported by SWPA as possible St George radar.
Dec 31, 43	192 mc 190 mc	1000 cps 1000 cps	Reported by SWPA as possible Cape St George radar.

The analysis report put out by Section 22 to amplify this collection of data stated:

> Definitely established air warning radar, verified by photographs as being located on high ground near tip of Cape St George. Frequency is averaged as 101 megacycles, and is checked closely by SWPA [Southwest Pacific Area, US Navy] report of 105 megacycles. Pulse Repetition Frequency is reported at 800 to 1,000, and may be assumed to be 1,000, common in Jap Mark I [Model 1] Type 2 radars. This radar installation has been bombed on numerous occasions, but to date is reported undamaged by intelligence summaries. This radar is thought to be still operating, but on an interrupted schedule. This station is important in that it provides warning for Rabaul against strikes from the east, but its importance is lessened by the fact that it may be supplemented by coast watchers during daylight hours.
>
> Signals on 192 and 190 megacycles reported by SWPA indicate a possible second radar in this area, although this unit is not found in photographs. Due to lack of evidence of controlled A/A fire experienced by pilots, the possible second radar may be for surface search [Author's note: the second radar was probably a Navy Mark I Model 2 transportable early warning set].

In January 1944 Ferrets VII and VIII arrived in the theatre and began operations. For administrative purposes they were attached to the 63rd Squadron of the 43rd Bomb Group, a Fifth Air Force B-24 unit based at Fenton Field near Darwin (21). Frank Witry recalled:

> We were sent to Port Morsby, New Guinea, and flew our first mission from there: we were in the air for about 8 hours, flying off the north coast of New Guinea where the Japanese had their radars. We logged several signals and took bearings on the radars. During this and later missions we searched the band below 200 MHz, with once in a while a search above to make sure there was not something new at, say, 350 MHz that we had been ignoring. Usually we flew alone but sometimes we would go along with the bomber outfit, to see if there was any special Japanese radar activity during attacks. We found none. (22)

VI

Still there was very little information available to the Allies on Japanese airborne radars. As late as January 1944 a US intelligence document noted:

> No Japanese airborne radars have been recovered; none have been photographed or seen, and in only one instance has a signal been heard which was believed to emanate from a Japanese aircraft ... The possible airborne radar frequency heard was during an attack by Japanese night fighters on a B-24 over Wewak [New Guinea] on January 19, 1944. The frequency could not be determined, but the ARC-1 search receiver operator in the bomber reported the pulse repetition frequency as higher than 700 cps ... (23)

In fact no Japanese airborne interception radar was operational at this time; either the linking of the radar signals with the night fighter interception had been a coincidence, or the signals were spurious. The only hard information on Japanese airborne radar so far had come from an aircraft mechanic of the 802nd Air Group taken prisoner during the capture of Makin in the Gilbert Islands in November. He mentioned that the Type 2 four-engined reconnaissance flying boats (Allied code-name 'Emily') belonging to his unit carried a device for detecting ships at long range. (24)

In the months to follow there would infrequent reports of Allied aircraft being intercepted at night, seemingly by Japanese fighters using airborne interception radar or homing on the bombers' own IFF transmissions. Concerning the latter, an intelligence report dated 1 March 1944 noted:

> (a) A bomber of the Fifth Bombardment Group (H) was tailed by two aircraft early in October just before daylight after a night bombing run in the Bougainville area. The aircraft followed so long as the Allied IFF was turned on and lost the bomber when the IFF was switched off.
> (b) The Fifth Bombardment Group (H) reported other instances pertaining to "triggering" in the Bougainville-Buka area. One of these concerned a bomber which was intercepted half way through a bombing run by seven enemy planes. The fighters were in formation and blinking their running lights. When they reached within 600 yards of our bomber the IFF was turned off. The bomber descended from 1,500 to 800 feet and the fighters were immediately lost. (25)

In spite of such evidence, however, it is clear from Japanese records and US post-war investigations that the Japanese fighters carried neither airborne interception radar nor equipment for homing on enemy IFF transponders. Since it is impossible in such circumstances to prove a negative, and enemy AI radar remained a distinct possibility, Allied intelligence officers continued to chase these will-o'-the-whisps. At the end of March an intelligence document issued by headquarters South Pacific Forces (26) stated:

> Interception of enemy AI radar is even more difficult than ASV [air to surface vessel] radar. It is best accomplished by a plane fitted with search gear flying into enemy territory, and permitting night fighters to home on itself to within a reasonable distance. At present, one RCM equipped SOPAC [South Pacific] Army Snooper plane is flying night missions with this in mind, but to date has received no enemy airborne signals. This is quite likely due to the present lull in enemy air activity.

With hindsight it is clear there were no Japanese night fighters with airborne interception radar in the area, but this in no way lessens the bravery of the B-24 Ferret crew which flew over enemy territory acting as 'live bait'. In 'permitting night fighters to home on itself to within a reasonable distance' the crew placed themselves in considerable danger: during a similar mission over Germany at the end of 1942, which established the operating parameters of the Lichtenstein radar, a Royal Air Force Wellington Elint aircraft was badly shot up and two of the crew were wounded.

VII

Following the capture of Kwajalein Atoll in the Marshall Islands in February 1944, US intelligence secured an windfall of documents which, at a stroke, more than doubled the number of enemy radars on which there was hard information (28). There were useful additional details on the two radar types photographed in the Rabaul area the previous November: the Mark I Model 2 mobile radar early warning set, described as operating on frequencies around 200 MHz (the badly damaged remains of one of these sets were found on Kwajalein); and the shipborne Mark II Model 1, whose 'bedspring' aerial had been photographed on the Japanese cruiser off Rabaul.

These confirmatory details were useful enough, but there was more: the documents gave brief descriptions of three important types of Japanese radar on which the Allied intelligence services had received had little or no previous hard information. The most intriguing tit-bit was a mention of the Mark II Model 2 surface search radar fitted to Japanese warships with an operating wavelength of 10 centimetres (29); it was the first indication that the enemy had a radar in service operating in that part of the spectrum. The documents revealed the designations of two sub-types of air-to-surface-vessel radar, the Mark VI Type 2 Special Model and the Mark VI Type 3 Special Model, and stated that both operated on frequencies in the 150 MHz band (30). And there were references to the Mark IV Model 1 and Mark IV Model 2 radars, both of which were described as land-based anti-aircraft fire control radars (31). All in all the documents constituted a most useful find, which added seven new designations to the Allied catalogue of Japanese radars.

The Allied advance continued, and with it the flow of captured radar material. In April 1944 ground forces found the receiver of an Air Mark VI radar on an airfield the Japanese had abandoned near Hollandia, New Guinea (32). Then in the following June, with the landings on Saipan, came more important finds. On one of the island's airfields troops found an intact Nakajima B5N2 torpedo bomber (Allied code-name 'Kate') complete with aerials and mounting racks for the Air Mark VI radar; and separately, in the same hangar, was the radar itself with a kit of spare parts (33). The aircraft and its radar were shipped back to the USA for examination; both were later flight tested and detailed reports issued (34). Elsewhere on Saipan US troops found a damaged Naval Mark IV Model 3 searchlight and fire control radar, the first Japanese equipment in this category to be examined by Allied intelligence officers. (35)

VIII

By the spring of 1944 it was clear that permanently modified aircraft such as the Army Air Forces Ferrets, flown by crews whose main role was Elint, were far more effective in finding enemy radars than the makeshift receiver installations on Navy bomber and reconnaissance aircraft operated by 'gypsy' crewmen. In recognition of this, Section 22 directed the formation of a dedicated Navy Elint unit equipped with two PBY Catalinas. (36)

In April 1944 Lieutenant Lawrence Heron, who had earlier flown as intercept receiver operator on some missions with Navy Patrol Squadron VP-104, received orders to form the Catalina Ferret unit. The modification of the 'Black Cats' took place at the seaplane base at Palm Island near Townsville, Australia (37). Fitting ARC-1 receivers into the aircraft was simple enough, but from first-hand experience Heron knew that a direction-finding aerial was essential if his unit was to be able to locate enemy radars. No suitable aerials were available at the time, so Heron and his men made their own out of Duralumin tubing. To make insulated mountings for the rotating aerials the Navy men melted the insulating material out of some spare co-axial cables, allowed it to set hard and then machined it to shape. (38)

Towards the end of April Herron's 'Black Cat' Ferrets began operations, flying initially from the seaplane bases at Port Morseby and Samarai Island to hunt for radars along the north coast of New Guinea. The area searched for enemy radars grew progressively wider, and towards the end of June 1944 'Black Cats' flew the first Elint missions to the Philippines. For these flights the Catalinas staged through a point near Cape Sansapor on the western end of New Guinea still in Japanese hands, to take fuel from a seaplane tender anchored in a deserted bay. (39)

IX

During the spring and summer of 1944 there was a crash programme at the main US fleet bases in the Pacific theatre, to install intercept receivers into all US warships liable to enter the war zone. Intended to provide warning of the presence of enemy radars and enable ships to conduct Elint searches in the course of their normal patrols, the standard suite comprised an APR-1 receiver and APA-6 pulse analyzer (40). The submarines found the new equipment especially useful, as one official US Navy release later stated:

> The ability to detect Japanese radars - shore, ship, and particularly airborne - long before the possibility of being detected by those radars even existed, meant a margin of safety which permitted submerging and other evasive tactics and saved any number of our underwater craft for further rampages among Japanese shipping. (41)

In August 1944 the submarine USS Burrfish took an underwater demolition team to reconnoitre beaches on Peleliu and Angaur in the Palaus group, in preparation for landings planned to take place there the following month; her captain's report (42) shows clearly the value of intercept receiver warnings in enabling her to avoid contact with the enemy and gauge the strength of the defences:

4 August
- 0430 Enemy radar on APR.
- 0500 More enemy radar.
- 2125 Enemy radar on 176 mc. Manned SJ [air search radar].
- 2157 SJ contact on port quarter 12,000. Clear lookouts from bridge. Lat 7° 04'N Long, 133° 55'E.
- 2159 Contact moved rapidly to a position down moon and commenced coming in. Plane sighted at 9,000 yards by OOD [officer of the deck], coming in.
- 2200 Dived with plane closing rapidly. Plane appeared to be a 2-motor bomber. His radar apparently had no trouble in staying on us and he was making a deliberate run from down moon. But for the APR we would have, at best, taken a close one. Especially since I did not turn on the SJ until after APR had contact.

10 August
- 2300 Dived for radar equipped plane in Lat 6° 45'N Long 133° 11'E. Had contact with plane on APR for 15 minutes during which time the signals became progressively stronger. Signal was very loud and steady when we dived. Note that weather was dark, overcast, with frequent rain squalls. Jap planes do not confine their patrols to clear moonlight nights.

11 August
- 0420 APR signal from land-based radar.
- 0530 Dived 10 miles east of Peleliu.
- 2025 Dived when two strong land-based radars came on trained in our sector. We were 8100 yards from the beach at this time.
- 2130 Came to APR depth - radars still on.
- 2355 Surfaced. No land radar operating.

12 August
- 1925 Came to APR depth - land radars are on.
- 2000 Tested again - radars on. Abandoned hope of surfacing close to the islands tonight.
- 2218 Surfaced - seven miles from land. Land radars on, but sweeping.

XI

By the summer of 1944 Allied intelligence officers had discovered a great deal about the Japanese Navy radars deployed in the South West Pacific theatre of operations. But at this time scarcely anything was known about the separate family of radars developed to fulfill the same tasks for the Japanese Army and widely deployed throughout the occupied territories in China, Indo-China, Burma, Malaya and the home islands. The intelligence attack on these was already in progress, however, launched in a completely different way and from a quite different direction: by the B-29 Superfortress bomber units making the first large scale raids on metropolitan Japan itself, from bases deep inside China. In the next chapter we shall see how these operations uncovered yet more Japanese radars.

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CHAPTER 11 SUPERFORTRESSES TO CHINA

In mid-1943 the US Army Air Forces began to receive the first examples of an important new strategic bomber: the Boeing B-29 Superfortress, which at the time represented the zenith of heavy bomber design and construction. With a maximum all-up weight of 67 tons, the B-29 was more than twice as heavy as the B-17 and the B-24 types it was to replace. The Superfortress was the first heavy bomber fitted with a pressurized cabin; and its defensive armament of twelve .5-in machine guns and one 20 mm cannon in remotely controlled barbettes was the most powerful yet seen (1). The B-29 could deliver 6,000 pounds of bombs to a target 1,700 miles from its base and return, carrying normal operational fuel reserves; no other bomber of the period came close to matching this superb performance. And, significantly for this history, the B-29 was also the first aircraft type to be delivered from the makers with space reserved for radio countermeasures equipment. (2)

As remarkable as anything else about the B-29 programme was the dispatch with which this revolutionary new heavy bomber was brought into service: the initial contract to build the aircraft was issued in June 1940 and the prototype first flew in September 1942. In June 1943 the first Superfortress unit, the 58th Bombardment Wing (Very Heavy), started to form to receive the initial production aircraft (3). By the end of November 1943 the XXth Bomber Command was formed, to take control of the Superfortress units forming at airfields in Kansas. The new bomber was to be used in the far eastern theatres of operations and plans were laid for the first B-29 Wing to move to operational bases in north-east India in the spring of 1944. At the same time forward bases were being prepared in China, from which the B-29's were to mount attacks on Japan itself. (4)

At this time Allied intelligence officers had little idea of the strength or the capability of the air defences on the Japanese home islands. Until now the Japanese radars had posed little threat to Allied air or naval operations, but it was clear there were many gaps in the intelligence picture of the enemy capability in this field. Obviously the Japanese appreciated the importance of radar for night operations, and had plenty of opportunity to learn of the Allied use of such equipment. It was not known to what extent German expertise and equipment were available to the Japanese; but submarines passed frequently between the two nations and it was generally felt that the Japanese would know about developments in radar and countermeasures in Germany (in fact, up to the beginning of 1944, technical co-operation between the Germans and the Japanese had been minimal; as their war situation deteriorated the Germans were more forthcoming with information and equipment, but the change of heart was too late to have any impact on the war in the Pacific). US submarines on patrol off Japan had picked up signals from low frequency early warning radars, and there were continual reports of intercepts of radar signals all the way up the frequency spectrum; concerning the latter, however, there were by now strong suspicions that many of these were harmonic indications of signals from lower frequency radars. In the Allied intelligence community the general view was that the Japanese probably did have radars more advanced than those discovered so far - possibly the German Wuerzburg or something like it - but these were being held back for the defence of the homeland. (5)

Also at the end of 1943 the APR-4 radar intercept receiver produced by the Crosley Radio Corporation, the Army Air Forces' version of the APR-1, began to emerge from the plant in Cincinnati in large numbers. For use with both types of receiver came a series of RRL-designed attachments: a family of tuning units fitted with motorized sweep, Types TU-56A, TU-57B and TU-58B, to cover the spectrum from 40 to 1,000 MHz; the APA-6 pulse analyzer with an associated audio oscillator to measure the pulse repetition frequency and pulse width of radar signals; the APA-23 recorder which electrically etched on paper tape the time and radio frequency of signals received, for later analysis; and the APA-17 and APA-24 direction finders. (6)

In April 1944 Superfortresses of the 58th Wing left Kansas to deploy to operational bases around Kharagpur in north-east India. One B-29 in four was to act as a countermeasures aircraft, initially carrying an APR-4, an APA-6 pulse analyzer and a crewman to operate them; some of these aircraft were also to carry the ARR-5 communications search receiver (the service designation now given to the ubiquitous Hallicrafters S.27). When they went into combat the Superfortress units would have to pick up intelligence on the enemy defences, and hope not to run into too many unpleasant surprises in the process. (7)

Dr Joe Pettit had worked at RRL on developments from the SCR-587 receiver and had been detached to the Crosley Radio Corporation to see the APR-4 into production. Early in 1944 he and another RRL engineer, Don MacQuivey, went to India with the 58th Wing as Technical Observers to oversee the US countermeasures efforts in the theatre. While there Pettit kept a detailed technical diary and sent frequent reports on what he saw to General McClelland, the Air Communications Officer at the Army Air Forces Headquarters in Washington. Fortunately for this history he retained his diary and copies of the reports, and kindly made them available to the author. Together, the documents convey a vivid picture of the unfolding pattern of operations and the difficulties which had to be overcome. On 15 May 1944 Joe Pettit reported to Washington:

> The planning for the [radio countermeasures] search program is actively under way. Not all the RCM equipment and officers have arrived in the four Groups. The Group personnel are rounding up their equipment and setting up storage and maintenance tents. Difficulty is expected in protecting the equipment from dust and from moisture when the rains come next month. Extreme ranges of temperature will be encountered in the combination of high-altitude flying and high temperatures on the ground. Shade temperatures at present run 105 degrees to 112 degrees Fahrenheit, but since the airplanes are in the direct sun the temperatures inside are probably well above 120 degrees Fahrenheit . . . (8)

Since January 1944 No 160 Special Flight of the Royal Air Force had been flying Elint missions from India and Ceylon using two modified B-24's. Joe Pettit made contact with the unit and learned that its aircraft had conducted missions along the coast of Burma, to the Andaman and Nicobar Islands, and to Sumatra. So far the only Japanese radar type positively identified in these areas was the well-known Navy Mark I Model 1 early warning set. (9)

The 58th Wing went into action for the first time on 5 June 1944, when ninety-eight B-29's carried out a daylight attack on rail yards at Bangkok, Thailand. To initiate the intelligence-collection effort, sixteen Superfortresses carried intercept receivers and radio countermeasures officers. The attack made it clear that some teething troubles remained after the hasty introduction of the B-29 into service: five aircraft were lost, none of them to enemy action. Afterwards Joe Pettit reported:

> Of the 16 RCM observers nine reached the target area with search equipment in operation. Of these, one was monitoring the 1.5 - 18 Mc range with a BC-348 receiver, two monitored 27 - 143 Mc with the AN/ARR-5, five the 75 - 300 Mc range with the AN/APR-4 and TU-58B and one in the 300 - 1000 Mc region with the AN/APR-4 and TU-57B.
>
> Only one or two satisfactory intercepts of the Japanese Mk I [Model 1] were obtained even though the flight crossed the Bay of Bengal where at least one Mk I installation is known to exist.
>
> Three operators logged a total of nine intercepts in the frequency range of 67 - 82 Mc. Of these, five had PRF's of 400 - 500, three were recorded near 200, and one merely estimated as "low". Pulse-length measurements were highly inconsistent, but the indications are of a relatively long pulse. This class of signals seems to correspond to the two stations previously discovered at Wewak, New Guinea . . .
>
> No signals resembling a German Wuerzburg have been reported, although only one receiver in this frequency range was in operation at the target of Mission #1. (10)

The 67 - 82 MHz radar was the Japanese Army Tachi-6 early warning set, which had first entered service in 1942 and was widely deployed throughout the home islands and occupied territories by mid-1944. The discovery of the radar at this late stage, when more than 200 were in service, is testimony to the inadequacy of the Allied Elint effort in the China and south-east Asia theatres up to the middle of 1944.

In his report to Pettit also discussed some of the countermeasures problems encountered during the mission.

> Some difficulties have resulted from the B-29 installation. Most serious is the location of the inverter [providing AC power for the countermeasures equipment] in the bomb bay, rather than in the pressurized cabin. A failure of the inverter, or one of the inverter fuses, renders the whole installation inoperative since a repair cannot be made in flight. Furthermore, on long missions when auxiliary bomb-bay gasoline tanks are carried, it has been necessary to shut down the inverter during periods of fuel transfer due to the fire hazard from the gasoline fumes. This results in periods of shutdown of the RCM equipment when search might be carried on . . .
>
> The [radio countermeasures] observer's operating position [on the seat of the aircraft lavatory] has proved uncomfortable and not conducive to good observations. Several of the men have obtained permission to remove the toilet and replace it with a salvaged radar operator's seat. On a search mission it is difficult to reach and observe the necessary controls of the several items of equipment, namely one or more receivers, pulse analyzer, and audio oscillator. A better rack arrangement may be desirable for future installations, even if it involves moving to a new location, e.g. opposite the radar operator. (11)

On 15 June the 58th Wing mounted its second operation, which was much more ambitious than the first: an attack on the Imperial Iron and Steel Works at Yawata on the Japanese island of Kyushu. This was the first attack on the enemy homeland since April 1942, when Lieutenant Colonel James Doolittle led a small force of B-25 medium bombers off an aircraft carrier to attack Tokyo. For the attack on Yawata the B-29's had to deploy to forward airfields near Hsinching in China, the nearest bases to Japan available to the Allies. Even so huge distances were involved: with a round trip of some 2,400 miles this was to be the longest-range aerial bombing mission yet made. One of the radio countermeasures officers who flew on the mission with the 40th Bomb Group was Lieutenant Tom Friedman:

> On the afternoon of 15 June sixty-eight B-29's got airborne and followed each other north eastwards towards the enemy homeland. We were scheduled to reach the target around midnight and attack singly, so there was no attempt to assemble in formation.
>
> As dusk fell I crawled back to the windowless, crowded radar compartment, to my position in the aircraft. The countermeasures equipment had been a late addition to the B-29's inventory and, in spite of its great size, there was little spare space inside the pressurized compartments. The racks for my equipment had been squeezed in between the bulkhead and the chemical toilet. As the twelfth man in the aircraft my "seat" was the lid of the toilet itself - a subject for numerous wisecracks on the appropriateness of my position!
>
> The carefully tested search gear was mounted in three racks in front of my "seat". My task during the mission was to monitor the range 75 to 300 MHz, with an occasional foray up to 500 to 600 MHz to see if the Japanese were using anything similar to the German Wuerzburg radar. A small electric motor, controlled by limit reversing switches, ceaselessly swept the tuning control of the APR-4 back and forth across the band I had selected. (12)

As his B-29 neared enemy territory Friedman started to hear signals from a Japanese radar on the APR-4. He switched off the sweep motor and tuned in the receiver manually, until at 80 MHz he could hear the buzz of the radar. Half a minute's work with the APA-6 revealed a square-topped pulse, 35 microseconds wide (13). The radar was an Army Tachi-6 early warning set, familiar to B-29 operators after the Bangkok raid.

> So our approach had been detected well before we reached the coast of China and several hours before our target. It remained to be seen what use if any the enemy would make of this information. As we neared the coast of China further signals came in from other early warning radars, on frequencies around 80 MHz and around 100 MHz. The strengths of the signals slowly increased until at times I thought we passed directly over the sites. (14)

The B-29 continued on towards the target, passing over the small island in the Strait of Tsushima which was the Initial Point for the bombing run.

> It was an eerie feeling to know that far below us our every move was being carefully watched on the enemy scopes and noted on their plotting boards. The $64,000 question was what could, or would, they do about it? Busily I logged the characteristics of each set of radar signals in turn, carefully noting the time of each so that after the flight the positions where the signals had been received could be plotted. The enemy radars in the target area included some of the 80 MHz sets I had picked up initially, the Mark I Model I set on 100 MHz (similar to the one I had seen at Eglin, captured on Guadalcanal) and there was some activity at 150 and 200 MHz which I took to be either gun-laying or searchlight control sets. I found nothing at all during my incursions into the 500 to 600 MHz band.
>
> Nearly a score of enemy radars were following us during our bomb run. From time to time I switched my earphones from the search receiver to the regular interphone and could hear the chatter of the gunners and the bombardier as they noted the searchlights' beams around us and the flashes of the bursting [anti aircraft] shells. (15)

At the end of the bombing run the B-29 pulled into a steep turn and set course for home. On the return flight Friedman logged a similar set of signals to those he had found on the way out, before the bomber regained friendly territory and the last of the enemy signals faded out. The bomber landed at Hsching after a flight lasting more than 14 hours. (16)

Seven B-29's failed to return from the Yawata mission, in each case due to accidents or mechanical failures. Analysis of the countermeasures operators' logs gave the first hard information on the Japanese radar network in China and the home islands. In his report to Washington Joe Pettit wrote:

> On 15 June combat mission #2 was carried out against Yawata on Kyushu Island. This was a night mission, the planes crossing the target around midnight local time. Of the 16 RCM observers 11 completed the flight with search equipment in operation, although one of these turned back short of the target. Nine of the observers searched the 75 - 300 Mc range with the AN/APR-4. Six observers searched 300 - 1000, during all or part of the time, with the AN/APR-4. One observer monitored 60 - 140 Mc with the AN/ARR-5.
>
> Results obtained in the 70 - 300 Mc range were quite good, the reports of the operators checking each other with good consistency. (17)

Pettit noted that the 75 MHz band signals - from the Tachi-6 - were obviously from an early warning radar and were heard strongly along the entire route over enemy territory. The countermeasures operators reported that this type of radar appeared to be tracking them: 'no variation in signal strength' (18). This is explained by the omni-directional transmissions from the Tachi-6, which produced a continuous signal on an intercept receiver (this type of radar used directional aerials only for reception).

> The Mk I radar at 100 Mc was heard over most of the route, particularly near the China Coast, Korea and the Japanese Islands.
>
> A few intercepts were made at 150 Mc. The PRF and pulse length do not check with similar intercepts in the S.W.P.A. [South West Pacific Area]. It is suspected that these may be second-harmonic responses from 75 Mc stations.
>
> A large number of signals were heard between 175 and 220 Mc. These signals were concentrated in the target area, off the tip of Korea, and in the vicinity of Nanking. Observations of the PRF are not consistent, this is perhaps accountable to the inherent difficulty of concentrations of signals during the relatively

> short time in the target area. The pulse lengths were relatively short. (19)

Almost certainly these signals were from the Navy Mark I Model 2 early warning set, and also from the Mark VI Model 1 and 2 and Tachi-1 and -2 searchlight and fire-control radars.

> Results in the range 300 - 1000 Mc were inconsistent. Of the six observers monitoring this band two heard only one signal each, while one reported numerous signals throughout the entire flight. It is suspected that some of the latter are spurious. It can be said, however, that no signals were checked by more than one operator. Also no signals were logged having the characteristics of the German Wuerzburg . . .
>
> There was no positive evidence of radar-controlled flak or searchlights. Anti-aircraft fire was stated to be moderate and generally inaccurate, and the fire seemed to be dependent upon illumination of the planes by searchlights. There were numerous cases of "coning" by searchlights, but only after one light had found the plane. The evidence is not definite that a GL [gun-laying] or SLC [searchlight control] type of radar does not exist, however. It would be suspected that the 175 - 200 Mc radars might be the ones intended for this purpose because of their concentration around the heavily defended areas. (19)

The initial attack on Yawata had taken the defences by surprise and their reaction was weak and poorly co-ordinated. Although the B-29's had been tracked for much of their flight and there had been more than two hours warning of their approach to the target, the anti-aircraft gun defences had been ineffectual and bomber crews reported no evidence of enemy radar-fitted night fighters (in fact the Japanese had none in service even on the home islands).

Following the Yawata mission the B-29's struck at other targets in Japan and Manchuria. The countermeasures operators' logs from these missions confirmed the impression gained during the earlier attacks: that the state of technology of the Japanese radars was about equal to that of Allied sets in 1941. For the time being these radars posed no serious threat to the heavy bombers, but there could be no doubt the attacks would spur the Japanese to improve the air defences of the homeland in any way they could.

The fifth mission was a night attack by 54 Superfortresses on 10 August, on the oil refinery at Palembang, Sumatra. This yielded a couple of interesting reports on the enemy defences, as Joe Pettit reported to Washington:

> One 200 Mc signal came on suddenly at Palembang, followed shortly by the appearance of twelve searchlights. This signal had a PRF of 1020 PPS and a pulse length of 6.4 microseconds. (20)

Almost certainly the radar involved was a Tachi-1 or -2 or a Mark IV Model 1 or 2.

> One aircraft was followed by night fighters. During the time of their presence two strong signals were heard at 177 Mc; these had PRF's of 1100 and 2300, with pulse lengths of 4.4 and 8 microseconds respectively. These signals may be an enemy AI [airborne interception] system based on triggering our Mark III IFF. One aircraft, in fact, reported night fighters attacking them off the west coast of Sumatra when their IFF was on, and losing them by turning off the IFF. (21)

Commenting in his diary, Joe Pettit gave his personal opinions on the reports:

> First, there was the incident concerning the 12 searchlights which suddenly appeared following the turning on of a 200 Mc signals (1020 pps, 6 micro secs) while the plane was in the vicinity of the target, Palembang. It seems that the searchlights did not succeed in "coning" the plane, probably because of the heavy undercast. Thus the evidence regarding SLC radar is "inconclusive" but not "negative".
>
> Second, there is the night fighter business. Apparently there was considerable trouble from night fighters off the west coast of Sumatra on the return trip. Field orders called for our planes to turn on their IFF on leaving the coast, presumably to provide

> identification to our cooperating naval unit. At least two planes . . . reported that the night fighters following them could be shaken off by turning off the IFF. This is exactly what was reported from So. Pac. and leads to two possible conclusions:
> (1) the story from So. Pac. has gotten around so well that they were influenced in their observations.
> (2) the Japs are actually using a type of AI based on an interrogator-responsor system like our SCR-729. This type of AI wouldn't be a bad idea (if we kept our IFF on), for a very low powered transmitter would suffice and the equipment could be quite light in weight. Time will tell. (22)

As mentioned earlier, and in spite of the sometimes convincing evidence to the contrary, it is clear from Japanese records that their night fighters had neither airborne intercept radar nor a device for deliberately triggering Allied IFF sets so that homings could be made on the reply signals.

II

Since his arrival in India in at the end of April 1944 Joe Pettit had pressed for a Ferret aircraft for the 14th Air Force, to seek out the Japanese radars in China and south east Asia. It soon became clear that no fully modified aircraft would be forthcoming in the immediate future from the USA: if such an aircraft was needed it would have to be modified in-theatre. On 29 May a B-24 was made available for modification and work began to equip the aircraft with two SCR-587 receivers, two ARR-5 receivers, two APR-2 auto-search receivers, two APA-6 pulse analyzers and direction finding aerials. After several problems the aircraft was finally ready on 12 August (23). On the following day it left for its operational base at Kunming in China, and during the months that followed the B-24 flew Elint missions to Formosa, the Pescadores Islands, Hainan and over much of Japanese occupied China.

III

The B-29's flying from forward bases in China continued to deliver attacks on targets in Japan until early in 1945. But almost everything required at the forward bases, including bombs and aviation fuel, had to be brought in by air; it was the shortage of airlift capacity, rather than strength of the Japanese defences, which restricted these early Superfortress operations. The ninth and final B-29 attack on Japan from China took place on 6 January 1945 (25). From then on the B-29's based in India and China attacked only less-distant targets in the Japanese occupied territories, until their departure for the Mariana Islands at the end of March.

Before we examine the next phase of B-29 operations, however, chronology demands that we return our attention to the counter-measures contest in Europe.

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CHAPTER 12 CRESCENDO OF JAMMING

In Europe, with the successful completion of the invasions of northern and southern France, the main concern of those in the Army Air Forces involved with countermeasures returned to that of providing sufficient Carpet jammers to protect heavy bombers from the worst effects of the German radar-controlled flak. In the mean time the frequencies of Wuerzburg had continued to spread, to an extent that became all too clear to those who received the weekly histograms issued by Gene Fubini's section at 8th Air Force headquarters.

In some squadrons one heavy bomber in four now carried APR-1 or crude ABL-15 'Pointer' receivers, so that the new APQ-9 version of Carpet could be spot-tuned on Wuerzburg frequencies not covered by the main barrage of jamming. But this necessitated specialized countermeasures crewmen on a quarter of the aircraft - suddenly vastly more countermeasures operators were needed than could possibly be trained at Boca Raton. It soon became clear that if the 8th Air Force wanted additional crewmen for this purpose, it would have to train them itself. Lieutenant Joe Wack described how this programme was implemented in his unit, the 488th Bomb Group with B-24's:

> Although there was now a requirement for an additional crew member to operate the Carpets on the modified aircraft, no trained men arrived at the 448th to perform this task. It became my responsibility to find volunteers for the job and train them to do it. Fortunately for my recruiting efforts I shared a Nissen hut with the squadron adjutant. Through him I had the ear of the squadron commander whenever I needed people, so there was never any difficulty. Some of the people I got were ex-radio

> operators who had completed their 25 missions and volunteered for a second tour. Others were ex-gunners who had become redundant when some of the gun positions were removed from the bombers because German fighters had become less of a threat. Others still were radio mechanics who wanted to get flying status. Almost anyone brave enough to volunteer to fly combat missions, and clever enough to learn the job, could become an RCM operator. Apart from me, nobody who did the job in the 448th had any prior training in RCM or knowledge of it.
>
> I flew on a few of the early missions with the spot-tuned Carpets, to discover how best to operate the jammers so that I could instruct the others. Once in the defended area we would sweep the receiver up and down the Wuerzburg frequency band until we heard the growl of a radar tracking the formation. We would then switch on a Carpet to transmit and adjust its frequency until we heard the sound of "rushing water" blot out the radar signals. The jammer was then on frequency. That done, we would examine each of the jammed frequencies in turn, and turn off the jammer for a brief pause to listen if the radar was still following our formation. In an area where there were powerful flak defences the RCM operator could be a very busy man. As we were sweeping through the Wuerzburg band with the receiver, we could often hear the "rushing water" sound as other aircraft jammed with their Carpets. (1)

The US strategic bomber units in Europe needed many more Carpets to cover the increasingly wide frequency band used by Wuerzburg. Yet although the jammer was being produced in large numbers, far too few of them were reaching the operational bomber units. What was happening to the remainder? Earl Cullum had been one of the members of RRL sent to England to assist with installing countermeasures equipment into warships for the invasion. Once this task was complete, and before he returned to the USA, he decided to visit a bomber base to see how the new batches of Carpets were being received. He was shocked to discover that scarcely any had arrived at the unit; other bomb groups told the same story (2). By this time about 500 Carpets had been installed in bombers in the European Theatre of Operations; but many of these aircraft had subsequently been lost in action and by this time only about 225 operational bombers carried the jammer (3). Cullum sent a priority signal to Pentagon reporting his discovery, which started an immediate investigation into the fate of the missing Carpets. They were tracked down to a depot at Cincinnati, where the officer in charge had no idea what they were for and was waiting for instructions on what to do with them. The jammers were immediately sent to the port of Newark, New Jersey, and loaded on the next available ship going to England. (4)

It was October 1944 before the dam finally broke and a torrent of Carpets began to reach the operational units. The table below shows the steep rise in the number of Carpet installations fitted to 8th Air Force heavy bombers (5):

8th Air Force, Number of Heavy Bombers Fitted With Carpet

		Barrage Jamming	Spot Tuned
1943			
	October	68	-
1944			
	February 16	125	-
	March	177	-
	May 21	approx 233	6
	July	165	31
	September 10	141	62
	October 10	120	81
	November 1	1342	126
	December 10	2746	147
	December 31	3460	507

The massive influx of Carpets into the 8th Air Force in October 1944 was followed by a similar rise in the number available to the 15th Air Force in Italy.

During 1944 there had also been a steady increase in the amount of Chaff used by the US strategic bombers over Europe, and by October consumption by the 8th Air Force alone was running at about 1,000 tons per month. By now sufficient was known about this countermeasure for Headquarters 8th Air Force to allow its subordinate Air Divisions complete freedom of action in its use. Bombers, carrying chutes to enable their crews to dispense large quantities of the metal foil rapidly, went ahead of the main formations to seed their path. Fighters released special canisters filled with Chaff, which broke up in their air to disgorge their contents. During this period 'way out' Chaff tactics were often employed, with the sole object of confusing the enemy gunners with new and unexpected effects. For example, on occasions the Chaff-dropping force would circle the target dispensing the material; on other occasions it would lay a Chaff trail along a course perpendicular to that of the main bombing force; on yet other occasions the Bomb Division attacking target A would dispense Chaff up-wind of target B, which another Bomb Division was to attack some ten minutes later (6). The decision had been taken to install automatic Chaff dispensing systems in replacement bombers to be sent to Europe, and these were eagerly awaited. But there were delays in the production of these units and until they became available every bundle of Chaff dropped from the heavy bombers had to be put out by hand. (7)

During the second half of 1944 the 8th Air Force lost approximately 1,320 heavy bombers to flak and only 438 to enemy fighters:

the trend indicated earlier in the year, that flak was the main threat, was now firmly established (8). Surprisingly there was no sudden reduction in the number of bombers lost to flak during the autumn of 1944, in any way commensurate with the huge and sudden increase in the number of Carpet jammers in use. Only somewhat later did it become clear why this was so: when jamming denied them the use of their fire control radars the German gunners would abandon predicted fire and resort to unaimed barrage fire against the US bombers (9). The cost of this in terms of ammunition expenditure was, however, enormous. For example during the attack through overcast by 720 US bombers on Hamburg on 25 October 1944, the forty-four heavy gun batteries surrounding the city fired 24,416 rounds of 88mm, 105mm and 128mm ammunition, almost all of it in barrages after the majority of fire control radars had been jammed out. The powerful cannonade caused the destruction of just one heavy bomber (10). Shortly after this action the German High Command issued orders that henceforth barrage fire was to be used only in the defence of specified targets of particular importance: if used generally it depleted stocks of heavy anti-aircraft shells faster than the German munitions industry could produce them. Following the implementation of the new order the effectiveness of the jamming in reducing the number of heavy bombers lost or damaged by flak, during bombing attacks through overcast, immediately became evident: this type of flak was now only one quarter as effective as when there was no jamming present. (11)

In spite of the success of countermeasures in reducing the overall effectiveness of radar-laid flak, there would be occasions when German gunners 'beat the odds' and inflicted heavier than usual losses on formations of attacking bombers. After the war one authoritative US report (12) stated:

> In the face of these various statements as to the effectiveness of our jamming, it is well to mention that our countermeasures were sometimes not effective. Many cases cited in German battle reports indicate that a certain number of flak radars would be able to track through even very strong jamming. Conditions such as siting, luck in picking a good [i.e. unjammed] frequency, wind conditions (as regards effects of Window motion on the "laus" devices [anti-Chaff modifications such as Wuerzlaus]), relative location and flight path of the attacking formations all entered into such occurrences. After strong jamming began, particular cases of tracking by a few radars still occurred. This is a natural conclusion when it is realized that radar control of flak was able to achieve an overall effectiveness of one quarter of normal.

The German reacted to the powerful increase in Carpet jamming in the autumn of 1944 by introducing an entirely new band of frequencies for the Wuerzburg and Mannheim radars: the C Band, running from 440 to 470 MHz. In order to keep the new frequencies secret - and therefore free from jamming - for as long as possible radar operators had strict orders to switch to the new band only if absolutely necessary (13). To counter the ever-increasing quantities of Chaff being dropped by the Allied bombers two new modifications were introduced for the flak-control radars: K-laus and Tastlaus. But although these were somewhat more effective than the earlier Wuerzlaus, dense concentrations of Chaff could saturate either of them (14) (For a description of the anti-jamming modifications fitted to Wuerzburg see Appendix E).

The increase in countermeasures activity by the 8th Air Force in England was followed by a similar increase by the 15th Air Force in Italy. It that theatre, however, the only RRL assistance was from the three technical representatives: John Foster (who during the Nixon administration would become Director of Research and Engineering at the Pentagon), Roger Avery and Robert Buss. In Italy there were few countermeasures-trained officers with the Bomb Groups and it fell to the RRL representatives to provide the necessary instruction for operators assigned to Carpet spot-jamming aircraft, nicknamed 'Panthers' in the 15th Air Force (15). When the RRL representatives began visiting units, however, it soon became clear that after the initial and obvious success of Chaff in the theatre earlier in the year there had been a marked decline in interest in countermeasures. The main reason was that the crews that had been convinced of their value, those flying missions at the time the countermeasure was introduced and who had seen an immediate reduction in the effectiveness of enemy anti-aircraft gunnery, had reached the end of their tours of combat duty and returned to the USA. Those who replaced them had little idea of what countermeasures could do for them. Reporting to Dr Terman, Robert Buss wrote:

> After working through the first two or three Bomb Groups, it became obvious that training Panther operators was only a small portion of a badly needed training program. In almost every Bomb Group, the conditions that existed were roughly as follows: the combat crews knew little or nothing about RCM. Rumors on the detrimental effect of this equipment were so bad that Chaff or Carpet at times purposely were not used. It is very doubtful if more than twenty percent of the equipment was

> being used. The ignorance of the crews was such that only a small portion of the equipment used could have been effective. The information given above was not readily available. It was not possible for a Technical Observer to obtain this information within a few days - if the normal methods were employed. The radar officer was seldom aware of these conditions. (The absence of RCM officers was responsible for a large portion of this trouble.) Most of the information was obtained by S/Sgt Burrell who as a seasoned GI was able to detect the real situation behind the "inspection front". (16)

In response to this clear requirement it was arranged that John Foster and Staff Sergeant Clifton Burrell would provide a series of lectures at the operational bomber bases in Italy, in addition to the instruction for spot-jammer operators. The move was an immediate success.

> Lectures were scheduled for all combat crews. Since most theaters only held six hundred persons at a time, several lectures had to be given at each Bomb Group. As the crews came into a theater there was considerable discussion as to whether it would be the usual ditching, escape or V.D. lecture. At these lectures the combat crews were told of the various forms of Radio Countermeasure and how they worked. The information given at these lectures was much more complete and everything was presented in a language that could be understood. Various German A.J. [anti jamming] devices were mentioned, and their operation dramatized by a "Fritz and Hermann Act". The current faults in crew procedure and negligence in operation of the equipment were exemplified by humorous and tragic incidents. All the information needed by a combat crew was given, but the presentation was such that the audience spent ten percent of their time laughing. A common remark made by any member of the crew was "Best damn lecture we've heard overseas". They were glad to be "let in" on some of the "secret devices" that were designed to save their lives. (17)

The lecture tour of bases in Italy lasted three months, during which the 1½ hour presentation was delivered before a total of more than 20,000 servicemen. The increased level of interest in countermeasures at the Bomb Groups produced some unexpected side effects: there was a flurry of complaints about 'wet Chaff' being issued before missions, as crews rejected material which earlier they would have accepted without question; and there were so many curious visitors to the countermeasures servicing sheds that in many cases these had to be enlarged. (18)

The RRL experience in Italy holds clear lessons for those charged with introducing countermeasures equipment into combat units and remain valid to the present day. Often there is a temptation to hide everything to do with electronic warfare under a cloak of secrecy and apply the 'need to know' principle over-zealously. But if this happens the chances are that, at best, aircrews will lack the understanding necessary to make use of the equipment; and at worst they will succumb to rumours that in action the equipment will 'act like a beacon' and simply leave it switched off.

II

At this stage the US jamming in the European theatre was concentrated entirely against the German radio controlled missiles and ground radars; there was relatively little interest in jamming enemy communications. While he was in England in the summer of 1944 O.G.'Mike' Villard discussed the matter with various service agencies, and set down his impressions in a revealing letter to Earl Cullum at RRL; he commented:

> It is sad to note that for all practical purposes, Tuba and Ground Cigar went down the drain. There is no great interest in jamming enemy fighters now - the operational people only want to get them up in the air so they can be shot down! And there

were no fighters in evidence anywhere on D-day. Curiously enough, no jamming from the German side was encountered on D-day either.

The desire to get fighters up in the air so they can be shot down explains why, for example, there is no interest at present in ARQ-8's or in communication jamming in general (with one exception). Please note that this theater has some ARQ-8's on order, although the present tactical situation is such that they would almost certainly not be used. The procurement people in Col. Dixon's office are a bit embarrassed about having a requirement in for some equipment for which there is no visible need. However, they have been persuaded into it.

The notable exception is, of course, the possibility of tank jamming. At present everyone seems to want 1 Kw Jackals for this job, but there does not seem to be any reason why ARQ-8's would not be just as good, except for the increased difficulty of operating the gear. Will investigate this further.

In the communications field, however, there seems to be a continuing need for voice recorders in this theater. The general idea is as follows: the 'Y' people who listen in on enemy fighter communications are getting a tremendous amount of information. The Germans carry on all conversations in clear, and it is almost possible for our people to direct our fighters on the basis of the remarks overheard. German-speaking operators are sent along with our formations, who write down whatever they hear so that the ground people can analyze it later in order to find out how Jerry is using his fighters. Now it frequently happens that these operators do not catch all that is being said, and that is where the recorder comes in. The recorder is switched on when an interesting conversation is heard. On the ground, the remarks can be fully transcribed and played over and over again if there is any doubt about a word or phrase . . . (19)

III

With the US radar jamming campaign in Europe now running at full spate, it is of value to compare its aims and tactics with those employed by Royal Air Force Bomber Command while attacking similar targets though mainly at night (9). The British No 100 Group (equivalent in strength of a US Wing) had the task of supporting bombing attacks and flew jamming support missions, night fighter escorts and Elint operations. (20)

In the jamming support role No 100 Group operated Stirling, Halifax, Flying Fortress and Liberator heavy bombers which flew Mandrel Screens, Window spoofs, jamming escort and target support operations. The Mandrel screen comprised six or eight aircraft orbiting clear of German-held territory and jamming with Mandrel on the enemy early warning radar frequencies, to conceal the approach of raiding forces; such screens were often flown when no bombing operations were planned, to maintain the pressure on the defences and preserve the value of this tactic (21). Window spoofs involved the use of a few aircraft releasing large quantities of Rope, to give the impression of large forces of bombers attacking diversionary targets. Jamming escort aircraft flew with the main forces of bombers, radiating jamming on the German night fighter VHF radio command channels. Target support aircraft orbited in the area of the main targets, radiating Carpet jamming on the Wuerzburg fire control radar frequencies. (22)

The night escort units operated two-seat Mosquito fighters which carried, in addition to AI radar, equipment to enable them to home on radar and IFF transmissions from German night fighters. As the bombers attacked, the Mosquitoes would orbit close to the fighter assembly beacons and airfields which the Luftwaffe was expected to be use during the night's operations. Although the Mosquitoes were unable to shoot down large numbers of enemy night fighters, they caused considerable disruption of the defences. (23)

Very few of the countermeasures tactics employed by the RAF No 100 Group were appropriate to the US day bombing operations, however. Apart from the target support operations the British jamming was devoted almost entirely to countering or slowing operations by the defending night fighter force, which posed the most dangerous threat to the night bombers; as we have already observed, such tactics could have little success by day because the defending fighters did not carry radar and were far less reliant on radar control from the ground. Only the target support operations were aimed at reducing the effectiveness of the defending flak batteries; and by day a few aircraft orbiting close to the targets for any length of time would have been extremely vulnerable. The countermeasures required to support day operations were quite different from those used at night.

Following its initial operations in support of Operation OVERLORD the 803rd Bombardment Squadron, the specialized radio countermeasures unit belonging to the 8th Air Force in England, underwent some major changes. First it was re-equipped with the more-roomy B-24 Liberator, a better aircraft for this type of work (24). Then in August 1944 it was re-designated the 36th Bombardment Squadron and moved to a new base at Cheddington north of London. During the summer the unit operated mainly with the RAF No 100 Group, taking part in Mandrel Screen operations in support of British night attacks. Not until 10 October did the 36th begin to support US daylight bombing attacks, with a Mandrel screen by seven B-24's to cover a small-scale leaflet dropping operation over Holland in bad weather. (25)

In November 1944 the Squadron began sending B-24's to orbit off the Dutch coast, to jam VHF frequencies used by American heavy bombers. The aim was to prevent the German radio monitoring service from obtaining useful intelligence while formations assembled over eastern England (26). For these VHF screening operations each B-24 carried five standard SCR-522 VHF communications radios fitted with noise modulators. From 25 November until the end of the war in Europe, the 36th Bombardment Squadron mounted almost daily VHF screening operations with up to ten B-24's. And, from time to time, the unit continued to take part in Mandrel Screen operations in support of Royal Air Force night attacks. (27)

Late in 1944 a small batch of ART-3 Jackal airborne communications jammers arrived at ABL-15 for use by the 36th Squadron. Don Reynolds, the ABL-15 representative working with the Squadron, had to make sure the jammer would not have similarly embarrassing side-effects if it was used in combat.

> Jackal put out about 1,000 watts, frequency modulated at an audio rate. It was a crude form of jamming, but very effective against an amplitude modulated receiver with no limiters - like the sets fitted to German tanks. We were afraid that the jamming might also interfere with US tank communications - there was some overlap between their frequency bands, but our tank radio sets used frequency modulation. So we flew some field tests using the jammer against captured German tank radios, with US tank radios nearby to see if they were affected. We found that the jamming had little affect on the US tank radios, it produced only a light buzz in the background, the operators could operate right through the jamming and get 10 to

> 15 mile ranges between tanks; that same jamming produced a screaming buzz on the German tank radios, which reduced their effective range to about ¼ mile. (28)

Not long afterwards there was an opportunity to use Jackal in action. In December 1944 the German army launched its final all-out counteroffensive in the west, with a massive attack intended to drive a wedge between American and British armies in eastern France: the Battle of the Bulge. After fierce fighting and substantial gains the German advance ground to a halt; then the Allied ground forces went over to the offensive to squeeze the enemy out of the salient. The 36th Bombardment Squadron supported these operations on 28 December, when it sent three B-24's carrying Jackal to orbit in formation over the Ardennes for a four-hour period jamming on German tank radio channels in the band 27 to 33 MHz. Accompanying these aircraft was a B-24 Elint aircraft of the same unit, to monitor the effectiveness of the jamming. The 36th Bombardment Squadron flew similar missions in support of Allied ground operations on 31 December 1944, and on 2, 5 and 7 January 1945. (29)

IV

While the support of the strategic bombing operations continued to be the main task for the ABL-15 personnel at Malvern, there were the occasional 'panics' which required immediate attention and diverted effort. One such occurred shortly after the invasion, when a German V 2 rocket launched from the test establishment at Peene-muende veered off course and headed north across the Baltic before it broke up in mid-air. The pieces rained down on neutral Sweden where, following some hasty bargaining, the British intelligence service secured the wreckage and flew it to England (30). A committee was formed to discuss the implementation of counter-measures against the new menace and ABL-15 was called in to assist. John Dyer, head of the laboratory since the previous April, described what happened next:

> Within a couple of weeks the pieces of the rocket found their way to the British test establishment at Farnborough for examination. The wayward rocket was found to be carrying a transponder to enable it to be tracked on radar, and receivers to pick up radio guidance signals; and that meant that the weapon could be vulnerable to jamming. I was brought into the so-called Big Ben Committee ["Big Ben" was the Allied code-name for the V 2], with a group under Robert Watson-Watt which met to consider what in the way of radio countermeasures could be employed against the missile. I was particularly impressed with the speed at which the British Intelligence people had been able to assess their find: the rocket's receivers had fallen in a swamp and, though they had been pretty badly beaten up by the time they arrived at Farnborough, they had been made to work and their characteristics had been determined. Still very little was known about the destructive potential of the V 2, but the British were very worried about it and assigned top priority to the provision of countermeasures. (31)

The transponder found in the rocket received signals on a pre-set frequency in the band 18 to 27 MHz, and transmitted on a frequency in the band 45 to 54 MHz. One of the other receivers was identical to that carried by the Henschel 293 glider bomb, used for the reception of radio guidance signals on one channel in the band 47 to 50 MHz (32); and a further receiver could receive signals on a channel in the band 46 to 54 MHz. From this, British intelligence officers postulated that the transponder provided the ground control station with an indication of the range of the rocket; that the missile could be radio guided in flight to follow a predetermined trajectory; and the remaining receiver was probably to vary or stop the fuel supply to the rocket motor, or possibly detonate the war-head if the missile began to wander off course. (33)

On the basis of this intelligence the 50 Kw RRL-designed 'Elephant Cigar' transmitter at Brighton - originally intended to beam communications jamming against German aircraft over Normandy but never used - was modified to transmit high powered jamming against missile-control signals in the band 19 to 40 MHz. Nearby, a further jamming site was set up using less powerful British broadcast transmitters requisitioned for the purpose (34). To protect the British capital against a large scale attack by V 2s, possibly with several rockets coming in simultaneously with guidance signals on different frequencies, many more high powered jammers would be required and these were not available from normal British sources. ABL-15 sent an urgent request to the USA for several of the RRLdeveloped high powered ground communications jammers held in reserve to be shipped to England at the highest priority. Some twenty GRQ-17's (a modified RCA broadcast transmitter with an output of 50 Kw, able to jam frequencies in the band 20 to 55 MHz) and the MRT-1 Cigar (15 Kw, 38 to 55 MHz) were rushed across the Atlantic. (35)

The first V 2 rocket fell on London on 8 September, followed by many others during the weeks that followed. The reinforcement of high powered jammers from the USA had not yet arrived, but the available jammers including Elephant Cigar radiated 5-second bursts of jamming on frequencies around 50 MHz whenever British ground early warning radar stations observed incoming rockets. British countermeasures experts hoped the jamming might disrupt the missiles' guidance systems. But ground monitoring stations picked up no signals that could be positively linked with the V 2 firings, and after a week the jamming was stopped to enable the monitors to conduct a more-careful search for transmissions going to or coming from the rockets. (36)

No such radio signals were ever found - because as we now know there were none. What the Allied intelligence services did not know, until very much later, was that the V 2 carried a crude form of inertial guidance system. It flew a pre-set ballistic trajectory independent of ground transmissions and was, therefore, invulnerable to electronic jamming. As luck would have it, the missile which crashed in Sweden had been testing the radio guidance system for 'Wasserfall', a first generation surface-to-air missile system based on the bombardment rocket; this had put the British intelligence service on the wrong trail (37). So the plan to use radio countermeasures against 'Big Ben' came to nothing. The resources diverted to this effort had not been large, however, and in time of war such risks have to be taken if there is to be any chance of countering a new enemy system soon after its introduction. The reader will observe later, however, that had the war in Europe continued into the summer of 1945 the jamming equipment assembled to counter the V 2 might have had an extremely important role to play.

Gradually ABL-15 became better known as a place where operational units could obtain answers to questions worrying them concerning electronics. Joe Pettit, who joined the laboratory after his return from India where he had assisted with the B-29 operations, described the sort of phenomena ABL-15 was asked to investigate:

> One of those I remember concerned reports we were getting from the bomber units, that sometimes during daylight missions their aircraft were tracked by enemy searchlights and then subjected to particularly accurate flak. Might the 'searchlight' be some form of radar working on optical frequencies? It sounded very unlikely, but it was our job to investigate such stories to see if there was any substance in them. The Laboratory built a simple optical electric cell, a demodulator, an audio amplifier and a pair of earphones through which the operator could hear the pulsing of enemy signals if there were any. The device was designed, built and flown over Germany within a few weeks of our having received the request to investigate the phenomenon. As we had expected, we found no evidence that the Germans had produced an optical radar. Almost certainly the "searchlights" reported by the bomber crews had been mistaken for the sun reflecting off patches of water, and the accurate flak had been optically laid. (38)

During the summer of 1944 ABL-15 sent a small team of Technical Observers to France to assist with electronics-related problems which arose there. One of its tasks was to supply the so-called 'Posit' teams attached to each US Army Group, operating receiving equipment to search for signs that the Germans were employing countermeasures against the newly introduced radio proximity-fuzed shells. ABL-15 assisted with this project until trained men could be sent from the USA; the assignment was only a precaution, in fact the Germans never attempted such jamming. (39)

V

By January 1945 the US heavy bombers and their escorts, backed by a considerable electronic superiority, ruled the skies over Germany and her rapidly shrinking empire. Yet although much had been achieved the Allies knew enough about their adversary to realise that it would be imprudent to rest on their laurels: until the very end, they could never be certain that the Germans were not about to introduce some new and previously undiscovered 'secret weapon' to swing the balance in their favour.

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CHAPTER 13 THE END IN EUROPE

By the beginning of 1945 the use of electronic jamming and Chaff by the US heavy bombers over Europe was on such a massive scale that it swamped every counter-countermeasure fitted to the Wuerzburg and Mannheim fire-control radars. The real answer to the German gunners' problems was an entirely new type of radar for flak control, one working on centimetric wavelengths which would be far less vulnerable to countermeasures. In fact the Germans had begun to develop centimetric radar only at the beginning of 1943, following the discovery of a 3,300 MHz H2S bombing radar in the wreck of a British bomber which crashed in Holland (1). Before then German scientists had done no serious work on microwave radar, and the sudden revelation that the enemy had such radars in service came as a profound shock to the German scientific community. The armed forces launched crash programmes to develop centimetric radars for flak control and lightweight airborne sets for night fighters and bombers. But by this stage of the war the German electronics industry was under considerable pressure to meet orders for existing types of radar; and as the Allied radio countermeasures began to take effect technicians had to be pulled away from work on new types of radar in favour of work on anti-jamming modifications to enable existing radars to continue operating. The destructive Allied bombing attacks and the continual drafting into the armed forces of men fit enough to fight, regardless of their industrial qualifications, did nothing to help matters. Thus it was not until the end of 1944 that the prototype of the first German centimetric wavelength flak control radar system, the Egerland operating on frequencies around 3,300 MHz, began operational tests at Schuandorf near Berlin. Initial tests showed that the new set was a considerable improvement over earlier ones and the Luftwaffe placed a top-priority order for a thousand of these radars. (2)

Egerland was still a long way from large-scale service, however; in the mean time the battle continued between Carpet in its various forms and Chaff, on the one side, and Wuerzburg and Mannheim on the other. Towards the end of 1944 the more-powerful APT-5 version of Carpet, with a power output of 15 watts, reached the bomber units in Europe. Lieutenant Joe Wack described the situation at his unit, the 488th Bomb Group, at the beginning of 1945:

> One quarter of our B-24's carried APQ-9 Carpets with operators, the other three quarters continued operating with pre-tuned APT-2's barrage jamming as much as the Wuerzburg band as possible. Towards the end of the war we received a few APT-5 Carpets, which developed three times as much power as the earlier APT-2 and so could cover a wider spread of frequencies. As APT-5's arrived in ones and twos they replaced the APT-2's, though the latter set continued in use until the end of the war.
>
> There were mixed feelings in the Group regarding the usefulness of RCM. Some of the older hands would say "Glad to have you aboard; you're helping keep down losses compared with what we used to suffer from flak." Others, especially the newcomers who had not seen what the flak was like before there was Carpet protection, remained skeptical and did little more than tolerate our presence. (3)

By this stage of the war the regard for countermeasures varied greatly from unit to unit; as always, much depended on the opinions of individual commanders. One notable enthusiast was Brigadier General H. Turner commanding the 40th Combat Bomb Wing of the

8th Air Force operating B-17's. Realising that Chaff did little to protect the aircraft at the head of the formation, he came up with the idea of sending a few high speed Mosquitos to lay out Chaff lanes ahead of the bombers. By following an undulating course in the target area the Mosquitos themselves would be in little danger from flak. Lieutenant Les Slote, a Boca Raton graduate assigned to the Wing, told the author:

> We fitted an automatic Chaff dispenser in the bomb bay of a Mosquito, but the darned thing never worked. Either the g forces were too great or the mechanism wasn't adequate but it would always jam, we could never get the Chaff out. So then we experimented with a couple of P-51 drop tanks each loaded with Chaff, fitted under the wings of the Mosquito. These Chaff "bombs" could be released in the target area and would break up to release their Chaff. I worked out a method of cutting the tanks longitudinally and using the metal straps used for straw bales to hold them together. And that worked. On several occasions the Mosquitoes were sent ahead of the bombers to release their Chaff "bombs". About four Mosquitoes would be used dropping eight "bombs", and that was enough. This cut losses, there was much less flak damage. (4)

With the strategic bombers well able to provide their own countermeasures protection over targets the task of the 36th Bombardment Squadron, the 8th Air Force's specialist countermeasures unit, was relegated to providing the VHF screens described earlier to prevent the German monitoring service listening in to the radio chatter from bombers during formation assembly over England. During February 1945, for example, the 36th mounted VHF screening operations on 24 out of the 28 days in the month, flying between two and nine sorties each day (5). In March the Squadron received three 'Droop Snoot' two-seater P-38 Lightning fighters, fitted with intercept receivers for Elint operations; during the final months of the war in Europe these were active over occupied Europe, co-ordinating their activities with the Elint Mosquitoes of the Royal Air Force's No 192 Squadron. At least one of the P-38's carried the new APR-7 microwave receiver developed by RRL, to search for the long-expected German centimetric-wavelength radars (6). From time to time Allied Elint operators did record centimetric-wavelength signals not originating from friendly radars, but such intercepts were infrequent and no German centimetric-wavelength radar was positively located by the Allies before the end of the war in Europe.

II

During the closing stages of the war the German armed forces were able to make little use of radio countermeasures against the Allies. Commanders were all too aware of the possibilities but, for reasons already discussed, the German electronics industry was under such pressure that there was little capacity to spare for work in this field. German bombers dropped Chaff and in carried jamming transmitters for protection against radar laid gunfire and night fighters; but these were ineffective against the centimetric-wavelength radars now in large scale use by Allied forces.

III

To the end of the conflict ABL-15 continued to develop new systems to meet needs perceived by front line units. John Dyer described one such device, 'Perfectos', along the lines of the IFF-homer it had been thought Japanese night fighters might have been using in the Pacific theatre.

> One interesting requirement that came in early in 1945 was for a means of locating the German Messerschmitt 262 jet fighters at long range, so that our fighters could home in and destroy them. The British had developed a device called "Perfectos" for their night fighters, which radiated an interrogating signal on the frequency used by the German IFF sets; the device also picked up the reply signals from German aircraft in the vicinity and enabled the night fighter crew to home on them. The "Perfectos" idea suited our purpose, but we needed a somewhat greater range than that provided by the British device. Using components from an SCR-729 and a Navy ASB radar, we developed our own version which gave ranges of around 100 miles - enough for our purpose. Our "Perfectos" was installed into a Mosquito obtained from the British and operational tests began; but unfortunately our Mosquito was shot down by "friendly" fighters on its second mission. We built another homer and fitted it into a two-seat P-47 operated by the 56th Fighter Group which, during the final days of the war, led single-seat P-47's in for the destruction of Messerschmitt 262s on a couple of occasions. (7)

ABL-15 also installed 'Perfectos' into a two-seat P-51 Mustang, but hostilities ended before this aircraft could go into action.

The Germans surrendered in May 1945, and almost immediately ABL-15 began to transfer men and materials back to the USA. The victorious Allies sent teams of experts to scour Germany for information on the latest technical developments and question German radar officers and technicians of all ranks, and experts from industry, on the work they had been doing and the effects of Allied jamming. From their answers it was clear that the massive use of countermeasures had indeed swamped the flak control radars (8). Generalmajor Vieth, who had commanded the Flak School Division of the Luftwaffe, remarked to his interrogators:

> Jamming became really serious after October 1944 . . . Chaff gave some trouble commencing in the autumn of 1943, but these difficulties had to a certain extent been overcome . . . as a result of active [electronic] jamming radar at times became completely useless, and in such cases [when firing was conducted under non-visual conditions] Flak did not go into action at all as the practice of barrage firing had to be given up. (9)

Fifteen Wuerzburg radar operators from flak batteries in different parts of Germany were asked about the proportion of occasions they had been able to track bombers successfully in the presence of both Chaff and electronic jamming. The replies varied greatly, from five of the operators who said 'none of the time' to one operator who claimed he had been able to do so 80 per cent of the time. Only he and one other operator said they could do it more than 50 per cent of the time. Averaging all of the replies, including the extreme values cited, the interrogators concluded that in the face of the two types of jamming tracking was possible only about 30 per cent of the time. Similar questioning of three Mannheim radar operators drew an average response of 20 per cent of the time. (10)

After the war Robert Soderman and Richard O'Brien from ABL-15 put together a comprehensive report entitled 'Intelligence Information on RCM Effectiveness in the E.T.O.'. This is the definitive account on the effect of electronic countermeasures used by the US strategic air forces in Europe, and is a model of how such a report should be written. The full document runs to 80 pages; large sections of it are given in Appendix F.

Elsewhere in Germany Allied investigators discovered that at the end of the war the Germans were on the point of placing into production two types of radio command guided surface-to-air missile: Schmetterling and Wasserfall. Schmetterling (Butterfly) was a 14 foot long winged rocket-propelled missile, with a maximum speed of 470 mph and a range of 20 miles, weighing 970 pounds at launch of which approximately 90 pounds was warhead. Wasserfall (Waterfall) was a much larger and more ambitious weapon, actually a scaled-down version of the V 2 missile used to bombard London; it was nearly 26 feet long, had a maximum speed of 1,700 mph, a range of 16 miles and at launch weighed 8,400 pounds of which 200 pounds was warhead. (11)

The Luftwaffe planned to get the first three batteries of Schmetterling into service before the summer of 1945, and 70 of Schmetterling and three of Wasserfall by the end of the year (12). Had the weapons become operational, however, the programme which Allied countermeasures experts had hastily improvised in the summer of 1944 for use the V 2 bombardment missile would have found an operational use. It will be remembered that the jammers had been designed to counter the errant V 2 - actually a test round fitted with the radio guidance system for Wasserfall - which had come down in Sweden and whose wreckage had been taken to England. Without realizing it, Allied experts had prepared a family of ground and airborne jammers tailor-made to counter the next generation of

German anti-aircraft weapons. It does not happen often in war that one does the right thing for entirely the wrong reasons.

V

There can be no doubt that, during the final year of the war, the use of radio countermeasures greatly reduced losses of heavy bombers to radar-laid flak and increased the cost-effectiveness of the US strategic bombing force by a corresponding amount. Between September 1944 and the end of the war in Europe the 8th Air Force flew approximately 144,000 sorties and lost 1,100 aircraft to flak (13). The average loss rate for this type of mission was one-half of one percent, amounting to 150 aircraft during the period. To extrapolate such figures to estimate the number of aircraft saved by the various forms of countermeasures is however extremly difficult. Because it is almost impossible to prove a negative one cannot say for certain which bombers would have been shot down and which would have survived had there been no jamming. But there is reason to believe that the radio countermeasures saved between 400 and 450 US heavy bombers from destruction during the war over Europe (14), and between 4,000 and 4,500 trained aircrewmen from death or captivity. The cost of the bombers alone was about $150 million, or twice the cost of the entire flak countermeasures programme. By any standards it had been a highly effective investment.

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CHAPTER 14 COUNTERMEASURES AID THE ISLAND HOPPERS

By the autumn of 1944 the US amphibious forces were on the offensive throughout the Pacific, with a relentless island-hopping advance westwards. At the same time far-reaching plans were in train for the installation of active jammers in the larger US Navy warships. The ultimate aim was to fit the high-powered TDY jammer (frequency coverage at that time 350 - 800 MHz) in all battleships, aircraft carriers, cruisers, headquarters ships and certain destroyers (1). The production of equipment and its installation on such a scale would take many months, however, so in the interim and to cover the lower part of the frequency spectrum several ships were fitted with low-powered jammers originally designed for airborne use: the SPT-1 and SPT-4 (Naval verions of the APT-1 and APQ-2 respectively) and the APQ-2 in its original form. (2)

The US Navy opened its jamming campaign in the Pacific in September 1944 as part of operations in support of the landings on Peleliu and Angaur in the Palaus Island Group. During their preparatory bombardment the fire support group comprising five battleships, nine cruisers and 14 destroyers used adapted airborne jammers against Japanese early warning and anti-aircraft fire control radars on the islands operating in the 100 to 200 MHz band (3) (the TDY, carried on a few of the warships, could not then jam frequencies below 350 MHz). The Japanese had no radars on the islands for surface-to-surface fire control, however, so none of their sets posed any direct threat to US warships. The islands were quickly secured, and on one of them US forces captured almost intact a Navy Mark IV Model I AA fire control radar. (4)

In the following month, October, US Navy Task Force 38 with seventeen aircraft carriers supported by six battleships, 15 cruisers and numerous destroyers, launched a series of air strikes on Japanese airfields on Formosa. B-29's of the XXth Air Force in India joined in the bombardment. The attacks were intended to give the impression of softening-up operations in readiness for the invasion of Formosa, part of the deception cover for the landings on Leyte in the Philippine Islands planned to take place shortly afterwards.

The feint was entirely successful. As well as drawing to their destruction many of the aircraft based on Formosa, it forced the Japanese high command to commit the 'T-Buntai': its elite force of radar-fitted twin-engined torpedo bombers being held back on the home islands for the decisive battle against the US fleet. On the evening of 12 October about a hundred aircraft of the 'T-Buntai' took off from Kyushu and Okinawa to launch a large scale night torpedo attack with radar assistance on the US Task Force - the first of its kind ever attempted by the Japanese (5). Most of the aircraft involved were Navy Mitsubishi G4M 'Betty' bombers fitted with the 150 to 160 MHz Air Mark VI search radar. But there were also twenty-three of the new Army Mitsubishi Ki-67 'Peggy' bombers carrying the 200 to 209 MHz Taki-1 search radar - neither this aircraft nor its radar had previously been encountered by US forces

(6). The Japanese raiders arrived in the area of the warships to find heavy rain squalls which prevented effective torpedo attacks. However these same weather conditions did not hinder the radar- fitted Hellcats of night fighter squadron VF(N)-41 operating from USS Independence. The US fighters fought a running battle with the torpedo bombers and claimed five shot down (7); others fell to the guns of the US warships. A similar Japanese air attack on the following evening resulted in a hit on the cruiser Canberra and a very near miss on the aircraft carrier Franklin; this, for the loss of 42 or nearly half of the T-Buntai's aircraft. (8)

Although the night torpedo attacks achieved little success they caused a flurry of excitement in the US Pacific Fleet: the Japanese airborne radars operated on frequencies well below the cover of the high power TDY jammer; and the lower power jammers designed for aircraft use could not be guaranteed to conceal warships on the radars of bombers closing to short range to launch torpedoes. On this occasion the US warships had been lucky - the weather had been bad and the Hellcats had been able to spoil many of the attacks. Another time the ships might not be so fortunate. It was essential that US warships receive an effective high-powered jammer to counter the enemy airborne radars operating on frequencies in the 150 to 210 MHz band, and quickly. A cry for help reached Division 15 and Dr Guy Suits described what happened next:

> Somebody pushed the panic button and Division 15 was tasked with producing a modification of TDY to enable it to counter the [lower frequency Japanese] radars, as rapidly as possible. Under our sponsorship Albert Hull and his team at the General

> Electric laboratories redesigned the TDY magnetron to cover the lower frequencies and within a week they had hand-built fifty units. These were rushed to the Pacific by air and within two weeks of the initial request the first had been installed in ships and were ready to go into action. (9)

In 1944 the official term for the procedure to deal with such high priority orders was 'Crash Procurement Procedure'; the modern term 'Quick Reaction Capability' had yet to be coined, but there can be no doubt that the capability itself existed in full measure.

In the days to follow, off both Formosa and the Philippines, Japanese Army and Navy attack aircraft attempted further night torpedo strikes on US shipping but without success. During the early morning darkness on the 19 October, for example, the destroyer USS Leutze intercepted signals from an Air Mark VI radar of a Japanese aircraft shadowing the fleet and jammed it using SPT-4 (10). On the following night, as a destroyer Task Group was approaching Leyte Gulf, a force of Japanese torpedo bombers approached and the ships intercepted signals on several radars on frequencies between 152 and 157 MHz. The destroyers used SPT-4 to barrage jam this band and no attack developed (11). There were other similar incidents in the area, but each time the Japanese aircraft encountered jamming they broke away. It seems the Japanese radar operators did not know that if they closed to short range they could 'burn through' the jamming and the enemy ships would re-appear on their screens. Unless or until the Japanese aircrew learned better, the low-powered jammers adapted from aircraft sets would continue to provide US ships with adequate protection.

Throughout the summer and autumn of 1944 Section 22's B-24 and Catalina Ferrets flew numerous missions to the Philippine Islands to map the enemy radar chain and hunt for indications of previously unknown types of radar. In October a B-24 Ferret made the first unequivocal intercept of signals from a Japanese ship-borne radar (almost certainly a Mark II Model 1, 185 to 210 MHz), when the crew linked the bearing from their intercept receiver with the 'paint' of the ship on the aircraft's search radar (12). Some Ferrets now carried the APR-5 intercept receiver covering the band 1,000 to 3,100 MHz; its arrival in the theatre came the first reliable reports of signals from the Japanese shipborne Mark II Model 2 centimetric radar mentioned in the documents captured on Kwajalein earlier in the year.

Information on the Japanese use of anti-aircraft fire control radar was slow to come in. Although Ferrets intercepted signals from them on several occasions, it was not until October 1944 that a B-24 of the 868th Squadron, 13th Air Force, positively established that a 200 MHz Japanese radar at Balikpapan, Borneo, was directing searchlights (13) (probably a Navy Mark IV Model I). Soon afterwards signals from a 75 MHz radar at Takao, Formosa, showed characteristics which suggested the set might be used for controlling anti-aircraft fire (14) (almost certainly a Tachi-3).

The Elint activity around the Philippines increased progressively until the invasion of Leyte by US forces on 20 October. A few days before the main landings an Army Air Forces B-24 Ferret intercepted signals from a Japanese search radar on Suluan Island overlooking the entrance to Leyte Gulf where the troops were to go ashore. As a result of this discovery a party of Rangers landed on Suluan before the main invasion and destroyed the set. (15)

Also during the pre-invasion softening-up operations, US carrier-borne aircraft used countermeasures for the first time. Dive bombers attacking targets around Manila released Rope as they entered their dives, to counter two 200 MHz Japanese radars in the area which it was thought might be used for gunlaying. Afterwards crews reported concentrations of anti-aircraft bursts in the area of the Rope, but could draw no definite conclusions on the usefulness of the countermeasure. (16)

Synchronized with the landings on Leyte during the early morning darkness on 20 October, Ferrets VII and VIII dropped Rope and another B-24 jammed the Japanese early warning radar frequencies with APT-1 Dina, to simulate an attack on the neighbouring island of Mindanao (17). Although it appeared to have been correctly executed, the spoof drew no recognizable reaction from the defenders.

On the night of the 20th/21st, following the landings on Leyte, Lieutenant Lawrence Heron was airborne in one of his 'Black Cat' Catalinas on an Elint mission over northern Borneo:

> We started hearing a great many microwave radar signals. We were pretty sure they were Japanese, because no American ships were known to be in the area. We ducked below cloud and saw an enormous number of ships - which had a rather profound effect on myself and the rest of the crew. Nobody shot at us. Why they didn't discover us I was never quite sure, unless they thought it was one of their own planes. Probably they assumed that no American in his right mind would operate in that area! As soon as I got clear I originated a secret and urgent signal back to the Task Force. (18)

When he returned to his seaplane tender off Morotai the following morning Heron was angered to discover that the message had not been passed on, nor would it be, because other searchers in that general area had reported seeing no enemy ships. In fact the 'enormous number of ships' Heron and his crew had seen was Vice-Admiral Takeo Kurita's First Striking Force, the main fighting body of the Japanese fleet comprising seven battleships, thirteen cruisers and numerous destroyers. This powerful armada had left Singapore two days earlier and put into Brunei Bay on the north coast of Borneo to refuel, before moving on to engage the US fleet off the Philippines in what later became the Battle of Leyte Gulf. As a result of the lapse it was not until the morning of 23 October that Kurita's force, by then off Palawan Island and well on its way to the Philippines, was finally reported by US submarines. Subsequent investigations led to the officer who had failed to pass on Heron's signal being relieved of his command. (19)

Once US forces were firmly established on the Philippines there was effort to spare to knock out some of the Japanese ground radars on the area. Fitted with improvised homing aerials, B-24's of the 868th Squadron, 13th Air Force, began flying radar-busting missions. On 3 November one of the Liberators detected signals from a Japanese radar at Sibago Island in the Sulu Archipelago off the north-east of Borneo. The aircraft homed on the set, photographed it, then attacked it with bombs and machine gun fire. (20)

In a hazardous mission on the night of 14-15 December, twenty-four Catalinas of Nos 11 and 43 Squadrons of the Royal Australian Air Force flew into the heavily defended anchorage at Manila Bay to drop mines from low altitude (21). Supporting the force, Lawrence Heron flew overhead in a 'Black Cat' Ferret radiating APT-1 and APT-3 jamming, while his aircraft and an Australian Catalina released large quantities of Rope to confuse the Japanese defences. In the course of the action Heron's aircraft spot-jammed a total of sixteen enemy radars in the 100, 150 and 200 MHz bands. The radar countermeasures were highly successful and only one aircraft was lost. (22)

II

By the autumn of 1944 the US Navy was ready to begin using countermeasures on a large scale from its aircraft. Thirteen of the eighteen land-based patrol bomber squadrons in the Pacific theatre already had some aircraft fitted to carry the APR-1 receiver and one jamming transmitter (either an APT-1, an APT-3 or an APQ-2);

in addition, a few Liberators were fitted with APR-5 receivers to look for signals from suspected Japanese microwave radars (23). Carrier-based Avenger attack aircraft also received an allocation of active countermeasures equipment: each carrier air group received equipment for five aircraft installations comprising the APR-1, APT-1 and APQ-2, and two with the APR-2 and APR-5. (24)

In the months to follow there was much experimentation by US Navy carrier aircraft to evolve the most effective tactics against Japanese radars. During the air strikes on Shanghai, Hong Kong and Formosa, carrier aircraft made frequent use of Rope against enemy 200 MHz ground radars. Detailed records of the countermeasures employed during these operations appear not to have been kept, but evidently the tactics were considered successful because early in 1945 the Navy increased the allocation of countermeasures equipment to front line units: each squadron of carrier- based Avengers was to receive sufficient to fit five aircraft with APT-1 and APT-2 jammers; each squadron of multi-engined aircraft would get sufficient equipment to fit three aircraft with APQ-2, while forward area depots were to hold APT-1, APT-2 and APT-3 jamming transmitters for use when required. (25)

By February 1945 the huge task of procuring, transporting and installing this mass of additional countermeasures equipment was largely complete. During the daring series of air strikes at the heart of the Japanese empire, against targets around Tokyo to divert attention away from the impending invasion of Iwo Jima, the carrier air groups put the new equipment to good use. The excerpt below, taken from the Action Report of the USS Bunker Hill, is typical of those from the eleven large and five smaller carriers which participated; note that the aircraft involved in the attacks were all single-engined types:

> February 16, 1945. Five TBM's [Avengers] each equipped with AN/APT-1 pre-set to 198-202 Mc, attacked strategic targets and shipping in the Tokyo area. One of the five aircraft was equipped with APR-1 and APA-11 [direction finding antenna]. Each VT [Avenger] and VB [Helldiver] accompanying the five TBM's was supplied with S- and P-band Window [S-band, as then defined, was 1,650 to 5,200 MHz; P-band was 200 to 390 MHz]. Electronic jammers were used from land-fall to land's-end. Two hundred Mc and 10 cm Window was dispensed in the target area. No planes were lost to enemy action. Subsequent attack by seven more VB's, each carrying 50 sleeves 10 cm Window and 90 sleeves 200 Mc Window.
> Crew Comment: All AA bursts downwind. (26)

During this time there was an important addition to the US Navy oversea reconnaissance force in the Pacific theatre, with the arrival on Tinian in the Marianas of Patrol Bomber Squadron VPB-106 equipped with the new PB4Y-2 Privateer. This aircraft, developed from the PB4Y Liberator, was specially modified for long range maritime patrol operations and featured a 7-foot extension to the fuselage to enable it to carry an operating crew of up to fifteen. There were provisions for an extensive radio countermeasures installation which included the following: APR-1, APR-2 and APR-5 radar intercept receivers with pulse analyzers and direction finding aerials, ARR-5 and ARR-7 communications intercept receivers and APT-1, APQ-2 and APT-5 jammers. Not all of this equipment could be carried at the same time, but the standard mounting racks allowed for the interchange of intercept, analyzing and jamming equipment depending on the nature of the aircraft's mission. VPB-106 began operations flying barrier patrols of up to 16 hours in support of US Naval surface forces moving in for the assault on Iwo Jima. In addition to providing cover for the Task Force, the Privateers acted as flying communications centres and relayed messages between ships and assisted ocean-going refuellers to rendezvous with the ships they were to supply. By this stage of the war, however, the few remaining units of the once-powerful Japanese surface fleet rarely put to sea. As a result there was little opportunity for the Privateers to exploit their excellent electronic countermeasures capability. (27)

III

In parallel with the fitting of countermeasures equipment into the US Navy aircraft there was a similar programme to upgrade the signal intercept capability of ships. All warships of destroyer escort size and larger, including headquarters ships, were to carry the Navy RDO receiver fitted with pulse analyzer, panoramic adapter and direction finding aerials (all developed by NRL), and an SPR-2 receiver (a Navy version of the APR-5). The standard allocation of equipment for submarines was an SPR-1 (a Naval version of the APR-1 which it was to replace) and an SPR-2, and a pulse analyzer later to be supplemented with a panoramic adapter and direction finding aerials (28). The main purpose of the receiver installations was to provide warships and submarines with an intelligence gathering and radar warning capability; but early in 1945 a US submarine demonstrated that the receivers could also be used offensively.

By the end of January 1945 the Japanese air forces on the Philippines had been virtually destroyed, leaving large numbers of trained aircrew stranded on the islands. Four Japanese submarines were ordered to Luzon to evacuate them, but US Navy crypto-analysis experts were able to read the enemy orders and an ambush was prepared (29). USS Batfish (Commander John Fyfe), was one of four submarines ordered to block the Japanese move; she reached her patrol area in the Babuyan Channel off the north of Luzon on the 6th, and waited quietly for the three days that followed. Then, on the evening of the 9th, the submarine began a remarkable run of successes all initiated by intercepts of signals from the Mark II Model 4 air search radars fitted to Japanese submarines; during these actions Batfish used the APR-1 receiver (she had not been retrofitted with the SPR-1).

Batfish surfaced at 1823 hours on the 9th and just under three hours later, at 2110 hours, Radioman 2nd Class Hugh Lowder operating the intercept receiver picked up radar signals on 158 MHz with a pulse repetition frequency of 500. He informed the captain, and the SD air-search radar was switched on briefly to look for possible aircraft in the area. If found none: almost certainly the signals were coming from an enemy craft on the surface, either a ship or a submarine. The aerials for the APR-1 were fixed dipoles on either side of the conning tower, and their lobe pattern could be swung only by turning the submarine itself. Lowder recalled:

> To determine where the signals were coming from we swung the boat in a complete circle. Lieutenant Berman, the Communications Officer, worked out a bearing on the transmissions and we headed in that direction. Periodically we keyed our SJ radar for brief periods, we knew there was something out there but we didn't want to give ourselves away. (30)

Moving at 20 knots on the surface, during the next 40 minutes Batfish covered about 13 miles towards the enemy craft. Captain Fyfe's account in the boat's Action Report now takes up the story:

> 2250 SJ [radar] contact bearing 240° True, 11,000 yards. Commenced tracking. Target tracked on course 310°, speed 12 knots so went to battle stations and commenced approach . . . Saturation signals on APR at 158 mgcs which increased in intensity as range decreased.
>
> 2331 Commenced firing tubes 1,2,3 and 4 on 130° starboard track gyros practically zero, range 1850 yards torpedoes set for six feet using a 2° divergent spread. All missed.
>
> 2339 (10s - 40s) Four end of run explosions. (31)

Still the enemy craft continued doggedly towards Formosa, its crew seemingly oblivious to their peril. And still the craft's air search radar continued to belch out signals. Lowder continued:

> We would never have operated our radar like that, we put our set on only sporadically. We thought it insane of them to be running with their radar blaring away. And we were even more surprised when the boat took no action after our torpedoes went past it. (32)

Batfish continued to close the range, using SJ radar in short bursts to confirm the position of the enemy. Shortly after midnight Fyfe sighted his prey.

> 0001 With the range to target 1020 yards a Japanese I class submarine was clearly visible from the bridge. We were in a beautiful position - 90 track zero gyros so at

0002 Commenced firing tubes forward. #1 was a hot run in the tube, #2 hit, and number three passed over spot where the submarine sank. The hit was accompanied by a brilliant red explosion that lit up the whole sky and the target sank almost immediately. Radar indications on the APR ceased abruptly. This radar signal was apparently non-directional type, and probably anti-aircraft since we closed to 900 yards without this giving any indication that he was aware of our presence. Target disappeared from visual sight and on radar screen almost immediately, screws stopped and loud breaking up noises were heard on sound gear. (33)

The Japanese submarine, the RO-55, went down with all hands.

Batfish remained in the area throughout the 10th and at dusk on the 11th she surfaced. Soon afterwards her intercept receiver picked up signals from a 158 MHz radar with the same characteristics as those heard earlier. Again Batfish closed to visual range, and Fyfe's account continued:

2037 Sighted target from bridge at range 1,300 yards, identified as submarine with no shears, very low in water, and perhaps slightly smaller than our last target.

2043 With range to target 1,200 yards, on a course for a 90° starboard track, had made up my mind to shoot when the gyro angles decreased 10 more degrees to 10° left, when at

2043-30 Signal from APR went off and target dove. Changed course to left and speeded up, in the meantime trying to reconcile myself to the fact that I had lost this one by trying to wait for the theoretically perfect set up. Why he dove became a point of discussion because at

2105 Just one half hour later sound heard a swishing noise [on sonar] from general direction of target that was universally accepted as the sound of a submarine blowing its ballast tanks. At

2106 Sure enough, APR showed that 158 mgcs was back on and SJ made contact 8,650 yards, bearing 018° True. Whether the target heard us or thought he heard us; saw us or thought he saw us; had us on his radar or thought he did or just made a normal and routine night dive I don't know, but I do know that unless he has a radar detector that will intercept our SJ, he's going to have a hard time finding us this time. (34)

Again Fyfe closed on his prey and just before reaching a firing position gave orders to submerge to radar depth. Soon afterwards Batfish launched a salvo of four torpedoes. Fifty seconds later there was a loud explosion as the first struck the enemy boat, followed nine seconds later by a second and eight seconds after that by a third. That was the end of RO-112.

Batfish then moved to a new patrol area west of Calayan Island, where she spent the whole of 12 February without incident. Shortly after midnight, on the morning of the 13th, the APR-1 yet again indicated radar signals similar to those from Japanese submarines but this time on a frequency of 157 MHz. As during the previous action, the enemy boat dived just as Batfish was closing in to attack. The US boat waited quietly on the surface then, half an hour later, further radar signals announced that the Japanese submarine had re-surfaced. A quick burst on the SJ radar established its range at 9,800 yards. Batfish closed to 6,800 yards, then dived to radar depth; shortly afterwards she fired a salvo of three torpedoes from her stern tubes, one of which struck the target and exploded (35). Again there were no survivors from the enemy submarine, RO-113.

For their parts in the series of actions several members of the crew of Batfish received decorations. Commander John Fyfe was awarded the Navy Cross and Lieutenant Gerson Berman, the boat's Communications Officer who had directed the use of the APR-1 information so effectively, received the Silver Star (36). Although the ambush positions had been selected using information from decrypted Japanese signals, it should be noted that this intelligence had not been accurate enough to take Batfish to within effective SJ radar range - about 6 miles - of the quarry. In each case the bearings on the enemy signals from APR-1 had taken the boat to a point from which radar could be used for the final stages of the attack. Alone, Batfish's success in sinking three enemy submarines justified the entire cost of developing and producing the intercept receiver.

IV

During the latter part of 1944 the US Navy established firm doctrines for the use of radio countermeasures equipment on ships. The orders to the Pacific Fleet outlined the main priorities for the use of such equipment:

> As of December 1944, the principal enemy radar threat is the use of 150 - 160 megacycles for airborne radars in snoopers and torpedo planes. Barrage jamming in this band can be accomplished by modified SPT-4 (Rug) jammers on ships without RCM personnel. Spot jamming ships would also be required whenever barrage jamming is employed; these spot jammers should be on ships with RCM personnel, intercept receivers and jammers capable of jamming enemy signals between 100 - 160 megacycles.
>
> Recommended procedure is for RCM technical personnel to stagger-tune the barrage jammers to cover the 150 - 160 megacycle band. The frequency spread between jammers should not exceed 2.5 megacycles whenever possible. (37)

To obtain maximum warning of the approach of Japanese search aircraft it was important that US ships intercept and identify their radar signals as rapidly as possible. Destroyers operating as early warning radar pickets now carried radar intercept equipment and served in the complementary role of radio countermeasures pickets.

During preparations for the invasion of Iwo Jima in February 1945, Ferret and photographic reconnaissance aircraft established the presence of four Japanese radars on the island; three were early warning sets operating on 100 and 150 MHz, the fourth a Mark IV Model 3 anti-aircraft gun control radar on 200 MHz (38). There was no indication of any fire control radars suitable for directing shore batteries engaging ships at sea (in fact the Japanese had no radar in service suitable for this purpose, though Allied intelligence officers did not know this for certain). As in the case of the landing operations in Europe, jamming cover for the ships going close inshore would come from adapted airborne sets fitted to the bombardment-support landing craft (LCIG's), ten of which carried SPT-4 jammers pre-tuned to the frequencies used by the Air Mark VI radar fitted to Japanese aircraft. (39)

Following the opening bombardment of Iwo Jima on 16 February, US warships in the area maintained a continuous intercept watch for enemy radar activity on the islands. This established that in general the early warning radars operated intermittently and only at night after the main bombardments had ceased, probably to watch the US ships' dispositions. The single anti-aircraft fire control radar operated only at night and when US aircraft were present. By the afternoon of the 18th, the day before the invasion was due to begin, the naval bombardment had destroyed all of the radars on the island. Not until the night of the 19th, after the landings had begun, were signals from an Air Mark VI radar intercepted for the first time in the area. All the ships turned on their jammers and the lone shadower turned away apparently without gaining anything useful. (40)

V

By the end of March 1945 the XXth Bomber Command, operating B-29's from India or forward bases in China, had flown a total of 49 missions of which nine had been against targets in metropolitan Japan. In the mean time the XXIst Bomber Command had deployed to airfields on the newly captured islands of Guam and Tinian on the Marianas and it too opened its offensive against Japan. From the end of October 1944 to the end of March 1945 the XXIst Bomber Command flew a total of 50 missions of which 29 had been against Japan itself. During March and April 1945 the B-29 units of the XXth Bomber Command moved from India to the Marianas and were absorbed into the XXIst Bomber Command. (41)

Apart from a few early missions, until the first week in March 1945 the majority of B-29 attacks on Japan had been by day and all were from altitudes above 20,000 feet. At these altitudes bomber crews often found difficult weather conditions with high clouds, turbulence and strong winds which made accurate bombing difficult. One way out of the problem would be to attack from lower altitudes, but B-29's attacking in this way by day would be far more vulnerable to the enemy defences. At night it would be another matter, however. By now it was clear that the Japanese had no operational night fighters fitted with radar. And even though they had some anti-aircraft fire control radars in service, there were not many even for the defence of the home islands: almost invariably, when bombers were engaged by fighters or guns at night, they had first been illuminated by searchlights. With these factors in mind Major General Curtis LeMay, commanding the XXIst Bomber Command, ordered a radical tactical experiment. For a single maximum-effort night raid on Tokyo he ordered crews to attack from altitudes between 5,000 and 6,000 feet, beneath the effective engagement altitude of the enemy heavy anti-aircraft guns and where radar bombing would be considerably more accurate than from high level. Because enemy night fighters posed little threat, for this mission all gun positions except that in the tail were to be unmanned and have their ammunition removed. The 1½ tons thus saved, plus the reduced fuel load required because the bombers would not have to climb to high altitude, meant the B-29's could carry a bomb load twice as heavy as during previous attacks: six tons instead of three tons (42). Understandably the bomber crews did not greet the new tactics with wholehearted enthusiasm. Long schooled in the belief that safety from the enemy defences depended on their flying as high as possible, many felt that at low altitude the B-29's would be 'sitting ducks'.

In spite of the misgivings LeMay's new tactics proved successful. On the afternoon of 9 March 1945 a force of 325 Superfortresses took off from their island bases for the heaviest attack they had ever attempted. Accurately laid concentrations of incendiary bombs started huge fires which, by the time they burned themselves out the following day, had laid waste large sections of the Japanese capital. Although the Tokyo anti-aircraft gun defences were the most powerful in Japan, smoke from the great fires made it difficult to engage the bombers as they roared overhead. Thirteen B-29's failed to return from the attack; one was seen to go down over the target after being hit by ground fire, seven others were listed as 'missing' probably to the same cause, and the remaining five ditched on the way home and their crews were rescued. This loss represented just over 4 per cent of the attacking force, a figure comparable with that during earlier, less successful, attacks on Japan. From now on low altitude night attack became the primary means of hitting the enemy cities and in the ten days that followed Nagoya, Osaka and Kobe suffered similar raids (43). Still there was no recourse to active radio countermeasures to shield the bombers from the defences: although jammers were held in store at the bombers' bases, the time was not judged ripe to use them over the enemy homeland.

VI

In parallel with the bombing attacks there was a huge Elint effort to plot the positions of the many radars operating on and around the Japanese home islands and learn as much as possible about the operation of the air defences. Intelligence-gathering by the XXIst Bomber Command took many forms. Throughout the campaign a proportion of the attacking B-29's carried an APR-4 and a radio countermeasures officer. In addition five B-24 Ferrets operated with the 3rd Photo Reconnaissance Squadron, part of the Twentieth Air Force (44). These late-war Ferrets carried a comprehensive suite of electronic equipment:

Radar Search Receivers:
- APR-4 (40 to 1,000 MHz)
- APR-5A (1000 to 6000 MHz)
- APA-10 Panoramic Adaptor
- APA-11 Pulse Analyzer
- APA-17 Direction Finder
- APA-23 Radar Signal Recorder
- APA-24 Radar Direction Finder

Communications Search Receivers:
- ARR-5 (27 to 143 MHz - Hallicrafters S.27)
- ARR-7 (550 KHz to 28 MHz - Hallicrafters SX.28)
- ANQ-1 Wire Recorder (45)

The initial task of the XXth Air Force Ferrets was to map the enemy radars in the Nanpo Shoto chain of islands, which ran between Iwo Jima and Japan. Intercepts of enemy signals indicated several early warning radars on the islands whose locations needed to be established. During attack missions on metropolitan Japan from the Marianas the B-29's were usually routed to follow the island chain on their way north; although this gave the Japanese air defences long warning of attacks, it simplified navigation and any alternative routing would have greatly increased the flight times to and from targets.

To gather further intelligence on the Japanese air defences, during bombing missions B-29's flying with the attacking force often carried Nisei radio operators (Americans of Japanese ancestry) to monitor enemy fighter and fighter control radio frequencies; these aircraft carried ARR-5 communications search receivers and disk, later wire, recording equipment. (46)

Radio countermeasures officers regularly flew on B-29's engaged in weather reconnaissance, air-sea rescue and minelaying missions near enemy territory. These aircraft brought back much additional intelligence, and were able to show that there was little Japanese early warning radar activity and practically none by gunlaying or searchlight control radars when few aircraft were present (47) (this revelation would be duly noted by those planning tactics for the atomic bomb attacks). The Countermeasures Air Analysis Center at XXIst Bomber Command headquarters collected data on Japanese radar and radio systems from all sources and collated it to build a comprehensive picture.

US Navy submarines operating off the Japanese home islands also brought back a wealth of information. During her patrol off the southern islands from 16 February to 9 March 1945, for example, Bluefish (Lt Cdr G. Forbes) reported picking up signals from Japanese radars in several areas:

The Army Tachi 6 early warning radar:
77-79-81, 500, 20-23-28 (frequency in MHz, PRF, pulse width in microseconds). Contacted nearly every night while in the area. Bearings taken from different positions by swinging ship place this radar on the northern end of Amami O Shima.

The Navy Mark I Model I early warning radar:
110, 500, 1-2. 18 Feb. Signal weak, triangular pulse shape.'

The Mark I Model III Air and surface search radar:
154-155-160, 500, 10-12-15 Contacted nearly every evening after surfacing, and at other times during the night when close to land. This contact came in

strong on the night of March 6. A bearing taken by swinging ship placed this radar on the southern end of Kikai Jima. Irregular periods of sweep were noted.

The Air Mark VI airborne radar:

151, 1000, 12 17 Mar, Strong, Probably airborne, Apparently keyed at irregular intervals. (48)

VII

The Japanese made little use of metal foil to jam radar, 'Giman-shi' as they called it, following their initial use of this countermeasure in the autumn of 1943. On the few occasions Giman-shi was used, the strips were invariably dropped in small quantities from the few bombers taking part in attacks and as a result achieved little. On the night of 24 November 1944, for example, a force of aircraft estimated at less than five attacked Allied troops at Chengkung in China. During the raid one of the bombers released a small quantity of tinfoil strips 23-in long and 2-in wide, tuned to counter radars in the 225 MHz band. On this occasion the countermeasure achieved nothing, except to reveal the fact that the Japanese had conducted no proper Elint reconnaissance in the area beforehand: there were no Allied radars around Chengkung! (49)

From this and other pointers it was obvious that although the Japanese had not yet mounted effective radio countermeasures, a clear threat existed. Accordingly a radio countermeasures training unit, nicknamed the Anti-Jamming Medicine Show, was sent to demonstrate the effects of Chaff, Rope and noise jamming to operators at radar sites in the south-west Pacific theatre. A Royal Australian Air Force Hudson bomber was fitted with several jammers, an intercept receiver, a portable jamming simulator for lecture purposes and several types of Chaff and Rope; the aircraft operating crew was Australian, with two lieutenants from the US Army Air Forces and one from the US Navy to give the jamming demonstrations and advise radar operators on how best to overcome the effects of the various countermeasures. An account of one of the demonstrations stated:

> The next morning the Hudson took off on its first demonstration flight, while on the ground the radar operators huddled around several SCR-268 scopes. This was electronic jamming. During the two-hour demonstration they sweated and fumed, trying to track through the noise. At first the job seemed impossible, but by the time the run was over they were catching on, seeing through the grass and railings [the latter caused by pulse-locked jamming].
>
> In the afternoon they saw Window. Several kinds of Chaff were launched from the plane, first in small batches, then in big ones to show the different tracking effects. The men at the scopes found themselves profiting from their noise-jamming baptism. The Window symptoms were different, but the general idea was the same. They did tracking that afternoon that would have sent them yelling for the maintenance man 24 hours earlier. (50)

One valuable byproduct resulted from these 'Medicine Show' demonstrations: they made everyone conscious of the possibility of enemy jamming and they highlighted fundamental weaknesses in Allied radar operations. In New Guinea, for example, the Hudson caused quite a stir when its single APT-1 easily jammed all six SCR-268 radars controlling the anti-aircraft gun defences around one important position: all of the radars had been sited within six miles of the position and all operated on frequencies within 1 MHz of eachother. Previously radar operators had complained of their vulnerability to enemy jamming, but not until senior officers in the area witnessed its devastating effects was urgency given to re-siting the radars and spreading their operating frequencies. (51)

VI

During the six months between the middle of September, 1944, and March, 1945, the status of US radio countermeasures in the Pacific theatre had been transformed. Now front line air and naval units were keenly aware of the advantages of using passive intercept receivers, Rope and electronic jammers. The equipment, coverage and capabilities of the Japanese radar network were becoming well known and naval and air operations invariably exploited gaps found in the cover; where no gaps existed, they could be made by mounting air strikes on individual radars or using jamming to screen forces penetrating the enemy defences. The stage was set for the next step in the island-hopping war in the Pacific: the invasion of the strategically vital island of Okinawa, one of the final goals before the invasion of Japan itself.

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CHAPTER 15 CLIMAX IN THE PACIFIC

By the final week in March 1945 US forces were ready to strike at the strategically important island of Okinawa less than 350 miles from the Japanese home islands. At the same time the B-29 units of the XXIst Bomber Command on the Marianas, having been brought to their full strength of five Combat Wings, were mounting ever more devastating attacks on Japanese cities and industrial targets (1). The stage was set for the climax of the war in the Pacific, backed by the full panoply of radio countermeasures devices at the US forces' command.

Prior to the landings on Okinawa and the nearby islands, Elint had established the existence of about a dozen early warning radars in the area. These could cause little trouble to US naval forces, however, and the main threat was still from the radars carried by the Japanese patrol and torpedo aircraft. To counter these, in addition to the warships' jammers, some 30 landing craft adapted for bombardment support (LCIG's) carried SPT-1 and SPT-4 jammers. (2)

The initial landings took place on the Kerama Retto islands 20 miles south of Okinawa on 25 March and the Japanese Army and Naval Air Forces reacted strongly with day and night attacks against the concentration of US shipping, with many by Kamikaze suicide aircraft. These attacks became all the more ferocious after 1 April when landings began on Okinawa itself (3). Yet in spite of the large number of attacks there was surprisingly little Japanese airborne radar activity. Afterwards the RCM control officer on the headquarters ship USS Estes reported:

> The only airborne intercepts obtained during the nights of L-7 to L+4 [7 days before the initial landings to 4 days after them] were signals from the Mark VI radar (153,1000,8) [frequency, PRF, pulse width], although bogies were within the vicinity of Okinawa almost constantly during these nights few such intercepts were obtained. From a total of 36 raids in the above period, Mark VI intercepts were obtained on three of them. Signals were picked up when the bogies were 80 - 90 miles away and were received intermittently while they closed. No signals were heard after the enemy aircraft approached to within 15 miles of Okinawa. Look-through periods varied anywhere from ten seconds to six minutes, while the bogies were approaching. Periods between looks varied in a similar manner. Such tactics indicated that the enemy might be using his radar to find and then home on the island of Okinawa. Undoubtedly he was previously informed of the fact that we could jam his set. (4)

During the 30 day period following the landings on Okinawa, observers on Estes estimated that signals from the Air Mark VI and Taki-1 radars were intercepted on only about fifteen occasions in the area around the island (5). The reason for so few signals was that only the guide aircraft leading formations of Kamikazes carried radar, and these aircraft would turn back before they reached the US warships.

During the sea and air battle to secure Okinawa the radar and radio countermeasures picket destroyers patrolled in the most exposed positions around the islands, and suffered accordingly. Of the thirty-six destroyers which served as pickets six were sunk, thirteen seriously damaged and five suffered minor damage (6). It was well into June before the desperate Japanese resistance on the island began to falter.

Following the hard-fought actions around Okinawa there was a lull in the war at sea, as the US and Allied naval forces withdrew to repair and replenish and the Japanese gathered their remaining resources in preparation for the final battle to defend their homeland.

II

Also at the beginning of April 1945, senior officers with the XXIst Bomber Command on the Marianas decided to start making full use of the B-29s' radio countermeasures capability. No sudden increase in the effectiveness of the enemy air defences prompted this decision: the loss of 14 Superfortresses during the initial low altitude night attack on Tokyo on 9 March would not be repeated during any of the maximum effort raids in the four weeks which followed. Now the main consideration was that the Fifth Air Force and the Navy had already used electronic jamming and Rope against Japanese radars on the Philippines, Formosa and the home islands, so there was little point in holding back a weapon which the enemy already knew about. And anything the radio countermeasures could do to reduce B-29 losses would be worth while.

Since the opening of the B-29 attacks on the Japanese home islands the previous summer the air defences had improved somewhat, though they were still able to inflict only minimal losses on the raiding forces. The air defence of metropolitan Japan was the responsibility of the Army, which controlled most of the gun defences and day and night fighters assigned to the home defence task (7). The defence of the naval bases and larger seaports was a naval responsibility, however; and apart from exchanging some early warning information with the Army, the Navy operated an entirely separate defensive system with its own radars for gunnery control and its own fighters (8). The separate defensive systems were, of course, extremely wasteful in effort.

The main sources of early warning for Army air defence operations came from the Type A doppler warning system, the Tachi-6 static early warning radar (68 to 80 MHz) and the Tachi-18 mobile early warning radar (100 MHz); for the ground control of fighters these radars operated in conjunction with the few available Tachi-20 height finders (94 to 106 MHz). The Japanese Navy employed its Mark I Model I (100 MHz) and Mark I Model III (146 to 165 MHz) radars for early warning (for further details on the Japanese radars see Appendix G).

In fact, throughout the Japanese air defence operations, there was never any shortage of warning on the B-29 attacks: whether the bombers came from China or the Marianas, they had to make long approach flights in full view of radars in occupied China, or on the Nanpo Shoto islands and radar picket boats in position off the coast. (9)

For control of the searchlights and heavy anti-aircraft guns of 75 mm, 88 mm and 120 mm calibres, the main Army radars were the Tachi-1 and -2 (185 to 205 MHz), the Tachi-3 (72 to 84 MHz) and the Tachi-4 (187 to 214 MHz). The main Navy radars for this purpose were the Mark IV Models 1, 2 and 3 (187 to 214 MHz). Although the Japanese had fragmented their meagre research effort to produce several different types of searchlight and fire control radar, there had been little effort to spread their operating frequencies to make them less vulnerable to jamming. Moreover, even at this stage of the war there was a serious shortage of fire control radars and many anti-aircraft gun and searchlight units had none. Due to the shortage of anti-aircraft ammunition, batteries were forbidden to employ barrage fire; thus if targets could not be tracked on radar or illuminated by searchlights, the guns stayed silent. There were several instances where B-29 raids of more than a hundred aircraft were met with less than 100 rounds of heavy anti-aircraft fire. (10)

Two different types of airborne intercept radar and one for the ground control of night fighters were under development at this time, but none was yet ready for operational use. Thus all night fighter interceptions had to be made visually. From time to time searchlights would illuminate targets for night fighters, but this was incidental to their primary task of illuminating targets for the anti-aircraft guns. (11)

This, then, was the target for the countermeasures of the XXIst Bomber Command. By Allied standards none of the Japanese radars represented any technology later than about 1941, and most were first-generation sets of even earlier vintage. Against these, the B-29's were about to open a jamming campaign using equipment with 1942 to 1944 levels of technology. The Japanese early warning radars posed no real threat so the jamming was to be concentrated against the searchlight and fire control radars operating in the 72 to 84 and 185 to 214 MHz bands. (12)

The B-29's first used their countermeasures capability on 7 April 1945, during a two-pronged daylight attack against industrial targets on the main Japanese island of Honshu. The 73rd Bomb Wing with 107 B-29's was to attack the Nakajima aircraft engine plant north-west of Tokyo. At the same time 194 aircraft of the 313rd and 314th Bomb Wings were to hit the Mitsubishi engine plant at Nagoya. On this occasion, also for the first time over Japan, the Tokyo attack force would be escorted by P-51 Mustang fighters operating from Iwo Jima; the Nagoya attack force would enjoy no such protection. (13)

Between them the Superfortresses carried 247 jamming transmitters, APT-1 Dinas and APQ-2 Rugs. In addition the bombers took 13,000 bundles of Rope type RR-3/U, each 13-oz bundle containing three rolls of foil 400 feet long and ½-in wide with a 3-in square cardboard 'parachute' at one end. The B-29's flew in standard daylight attack formations, with nine to eleven aircraft per squadron and squadrons following each other at approximately half-mile intervals. Each squadron acted as a self-screening unit, with ten APT-1's pre-set to barrage jam the 185 to 205 MHz band, and two APQ-2's spot-jamming radars on frequencies outside the main barrage. To counter the Tachi-3 on 72 to 84 MHz, aircraft in the lead of each column of squadrons were to drop ten bundles of Rope per minute. (14)

Both raiding formations were heavily engaged by Japanese fighters and anti-aircraft fire and five B-29's (1.6 per cent of the force) were shot down. Three of the bombers are believed to have fallen to fighters, the other two fell to anti-aircraft fire. (15)

Following their use over Japan by day, countermeasures were also employed by the B-29's attacking at night. The night bombers attacked in a loose stream, however, with a far greater spacing between aircraft than by day. As a result there was a much lower concentration of electronic jamming and Rope in the target area. Initially the low altitude attacks had taken the defenders by surprise and on occasions as many as twenty searchlights would follow a single B-29 while the gunners engaged it with everything that could be brought to bear. This was sometimes fatal for the unfortunate crew but it meant scores of other bombers enjoyed a 'free ride' through the defended area. Quickly the Japanese searchlight operators improved their tactics: with the aid of a radar-controlled master light, one pair of lights would follow an individual bomber through the target area while others would seek new targets. To determine the effectiveness of Rope against searchlights the XXIst Bomber Command ran some experiments as Stanley Kaisel, the RRL Technical Observer attached to the Command, wrote at the time:

> On the [night] mission on 13 April 1945 to Tokyo Arsenal two aircraft of the 314th Wing [out of a total attacking force of 327] were supplied with [Rope type] RR-2/U and in one of the two aircraft it was found that when they were "coned" [held by two or more searchlights], throwing out ten bundles would cause the lights to drift off the ships to the rear. On the basis of this, 80 units each were placed in six aircraft [out of 194] for the 15 April [night] mission to Kawasaki. The men dispensing were briefed to throw out 5-6 bundles when a searchlight hit the ship, and to dispense at a rate of 1 unit per second when the flak looked dangerous. One [of the aircraft carrying Rope] failed to return, and four of the remaining five reported between three to six successful evasions of searchlights and were convinced of the efficacy of the the method. The fifth ship reported lack of success in two instances of "coning", but the gunner reported that at the time that rope was thrown out several other searchlights suddenly converged behind the aircraft. On the mission to Tokyo on 13 April 1945 the 73rd Wing reported that the use of rope caused searchlight and flak to be directed at the rope, the aircraft was untouched. Two separate instances of searchlight evasion were reported by the 73rd Wing on this occasion.
>
> The Commanding General has authorized full scale use of rope, but to conserve our meager supply outstanding directives to the Wings provide that it only be used at night or under conditions of poor visibility in the daytime. A regulation being issued states that 3 bundles of RR-3/U should be dropped every 10 seconds whenever the plane is in trouble from searchlights or flak. This should create a number of discrete echoes on the enemy radar, leading to temporary confusion. (16)

Bomber crews quickly realized that Rope could be very effective in ridding themselves of the troublesome Japanese searchlight beams and became very keen to use it. But supply fell far below demand in the Pacific theatre: during April the B-29 units received only 150,000 bundles against a monthly requirement of 1½ million bundles. As Kaisel told the author:

> At that time the European theatre still had the higher priority and supplies were limited. One interesting result was that aircrews became very "Rope conscious", they would remove unused bundles from their aircraft after missions and store them securely in their quarters; any bundles left in an aircraft were swiftly "appropriated" by other crews to increase their own supply. (17)

By May 1945 the improved Japanese tactics, coupled with the deployment of more fire control radars, led to an increase in B-29 losses during low altitude night attacks. This culminated on the nights of May 23 and 25 when the raiding forces over Tokyo lost 17 out of 520 (3.3 per cent) and 26 out of 464 (5.6 per cent) respectively. (5)

To provide electronic jamming against Tachi-3 radars operating in the 72 to 84 MHz band, B-29's began to carry ARQ-8's pre-tuned to barrage jam these frequencies. Bombers assigned to the spot jamming task carried three APT-3 jammers (later replaced by three APQ-2's modified for single-dial low-band operation). Work began on a programme to fit about half the B-29's as spot jamming aircraft, though because of shortages of equipment this would not be completed before the war ended (19). The increase in the number of spot- jamming aircraft meant there were insufficient radio countermeasures officers to operate the equipment and, as had been the case earlier in Europe, volunteer aircrewmen received a hasty training to enable them to perform this task.

Still there was insufficient density of jamming at the targets to protect the widely spaced night bombers, however. So the idea arose of operating special B-29's carrying large numbers of jammers in place of bomb loads, to orbit near targets and screen attacking forces as they passed through defended areas. Because the jamming B-29's had numerous blade aerials sticking out from their fuselages these aircraft were immediately nicknamed 'Porcupines' (20). The plan was to fit four aircraft in each Bomb Wing with sufficient equipment to jam all frequency bands used by the Japanese searchlight and fire control radars. With four such jamming aircraft flying separate patterns in random fashion over the target there was a good chance that at any given time a fire control radar in the area would have at least one Porcupine transmitting down its main lobe and the other three jamming its side and back lobes. (21)

That was the theory, but for a Porcupine B-29 to jam the entire band of frequencies used by the Japanese searchlight and fire control radars - 72 to 84 and 180 to 220 MHz - it would need to carry at least eight 200 MHz band jammers, five 78 MHz band jammers, some 2,000 bundles of Rope with provision for automatic dispensing, and two spot-jamming operators. To cram so much equipment into the B-29 posed problems of space, power supplies, cabling and location of the necessary aerials. Although two different layouts for this 'full Porcupine' fit were investigated no such aircraft would be ready for operations before the war ended. (22)

Pending the arrival of the ideal solution each Bomb Wing began work to modify four B-29's as 'interim Porcupines' carrying six or more jamming transmitters. The first became operational in June 1945, and in the weeks to follow others joined them to screen night attacks. During the four-Wing mission on the night of July 16, for example, the 73rd Wing sent 129 bombers to hit Oita supported by two jamming aircraft; the 314th hit Hiratsuka with 132 bombers supported by four jamming aircraft; the 58th Wing hit Numazu and the 313rd Kuwana, with 128 and 99 bombers respectively, but these units had no Porcupines with them and the bombers had only the protection of their own jammers. No B-29's were lost during the night's operations though several suffered damage. (23)

Soon four out of the five Wings of the XXIst Bomber Command were operating interim Porcupines, each modified to a different pattern, to support night missions. The 58th Wing, for example, adapted its countermeasures aircraft to carry three spot-tuned jammers and an APR-4 in the rear compartment, and ten or more pre-set barrage jammers in the bomb bay. Lieutenant Harry Smith, one of the unit's radio countermeasures officers, recalled his missions on board the interim Porcupines:

> For obvious reasons the RCM B-29's soon gained the nickname "Guardian Angels", and I flew several missions aboard them. The RCM operator's job was to switch on the barrage jammers at the correct time, then use his spot jammers to take out any enemy radars not covered by the main barrage. Normally the Guardian Angels would precede the main force of bombers to the target area, then begin jamming and fly racetrack patterns over the target at altitudes above 12,000 feet. The lowest Guardian Angel would orbit clockwise, the next one up counter-clockwise, and so on up the stack. Since we arrived in the target area first the gunners on the ground would start off by trying to engage us. That part of the mission could be very exciting and sometimes we took damage. But soon afterwards the

main force of bombers would come in at altitudes around 5,000 feet and they took the heat off us.

As soon as the Guardian Angel B-29's started operating there was a dramatic reduction in the number of aircraft lost or which returned with damage. Overnight the status of the RCM officer rose from "mere passenger" to "fantastic guy". After the success of the first such mission our Wing Commander became very enthusiastic and wanted the protection of Guardian Angels even when we were attacking targets where there were no threatening radars. Sometimes we could talk him out of the idea if it was a daylight raid. But at night he usually wanted us to go along even if there was nothing on the ground to jam; he would say "To Hell with that, the aircraft are modified so let's use them!" (24)

As well as the interim and full Porcupine programmes with the B-29, RRL Technical Observer Stanley Kaisel was also involved with installing an automatic dispenser for Rope into the aircraft. He told the author:

During missions the Rope had to be dispensed by hand through the camera hatch situated behind the rear pressurized cabin. This was far from satisfactory, especially if strike photos were required and the hatch had to be used for its intended purpose. But although Wright Field had been experimenting for some time they had failed to find a location for an automatic dispenser on the B-29 that satisfied all the requirements. We managed to get hold of an A-1 automatic dispenser on Guam and, after studying the B-29, concluded that the best place for it was in the unpressurized section of the rear fuselage, close to the camera hatch used for manual dispensing. But we were warned that 700 pounds of Rope, plus the dispenser itself, in that position would shift the aircraft's centre of gravity aft to a serious extent and would never get official approval. When we approached the operations people at XXIst Bomber Command, however, their reply was "We need the protection; you tell us where it will fit and we'll solve the weight and balance problem." The incident was a good example of the differences between the operational people who have to solve problems rapidly and pragmatically, and the research and development organizations who can search for years for ideal solutions to satisfy everybody and may never succeed. By the end of July 1945 we had completed the prototype installation of an automatic dispenser in the rear of a B-29 and had it approved. But the war ended before the full installation programme could get under way. (25)

III

The day and night fire raids were tearing the heart out of Japan's cities and systematically wrecking her industrial base. Yet worse was in store, however, with a weapon vastly more powerful than anything previously conceived about to be unleashed against that nation: the atomic bomb. Under the strictest secrecy a B-29 unit was making final preparations to carry out this new form of attack: the 393rd Squadron of the 509th Composite Group. The Squadron's Electronic Officer, Lieutenant Jacob Beser, was to fly on the atomic bomb attacks and found himself in the unique position of being able to choose the radio countermeasures suite he took on an operational mission. For the protection of his B-29 Beser selected a mix of APT-1, APT-4 and ARQ-8 jammers, for use if the bomber was engaged by accurate radar-laid anti-aircraft fire. As important as warding off possible Japanese ground fire, Beser had also to ensure there were no radars in the target area which might trigger the atomic bomb's radar air-burst fuzing system prematurely. To detonate them at an altitude of about 1,900 feet above the target, for maximum blast damage, the early atomic bombs each carried four separate radar fuzes: modified APS-13 tail warning radars (410 to 420 MHz) mounted around the circumference of the bomb with the directional aerials pointing forwards. As a back-up for the radar fuzes there was a barometric fuze set to the same altitude; and in case neither the radar nor the barometric fuzes functioned properly, the bomb carried mechanical impact fuzes in the nose and tail to set it off when it struck the ground. (26)

There was no intelligence information on a Japanese radar operating in the 410 MHz band which might interfere directly with the bomb fuzing radars, but there was always a chance that such a radar might be introduced. More likely, there was the possibility that harmonic signals from an enemy radar operating on, say, 205 MHz might be strong enough to trigger one of the radar fuzes during the bomb's fall and set off the weapon prematurely. If that happened there was a serious risk that the B-29 would be incinerated in the fire ball from its own bomb. To prevent this, during the bombing run Beser was to monitor the frequencies used by the bomb fuze radars with his APR-4 receiver. If there were transmissions which might have triggered the bomb, at any time up to bomb release he could switch off some or all of the fuze radars and, as a last resort, leave the detonation of the weapon to the barometric or impact fuzes. (27)

Jacob Beser was the only man to fly on both atomic bomb missions, against Hiroshima and Nagasaki on 6 and 9 August 1945 respectively. On neither mission did enemy radar controlled anti-aircraft guns attempt to engage the B-29; and at neither target did he detect transmissions which might have triggered the bomb prematurely. (28)

The two atomic bomb attacks brought the war in the Pacific to an abrupt halt, much to the relief of the soldiers and sailors preparing for the invasion of the Japanese home islands.

IV

During their fourteen months of operations against metropolitan Japan, from mid-June 1944 to mid-August 1945, Superfortresses flew a total of 277 raids with more than 27,000 sorties. Of these raids 116 involved less than fifty aircraft and 21 involved more than two hundred. B-29 losses known or believed from enemy action totalled 214 aircraft, or just under .8 per cent of those taking part. The causes of these losses were as follows:

Due to anti-aircraft fire	48
Due to fighters	58
Due to anti-aircraft fire and fighters	29
Due to unknown causes	79 (39)

The majority of B-29 losses to fighter attack occurred during daylight missions before US escorts became available in April 1945. Similarly most losses to anti-aircraft fire took place before the countermeasures campaign began to take effect. Following the introduction of the interim Porcupine B-29's to screen raiding forces at the beginning of June 1945, losses during the night attacks immediately fell: during the 2½ months from then until the end of the war, in the course of 103 attacks involving over 8,800 sorties, only 28 bombers were lost to all causes: only .3 per cent of those taking part (30). As with the jamming over Europe, it is impossible to calculate with accuracy the number of US heavy bombers saved over Japan by the use of countermeasures; we know the jamming caused considerable degredation of the Japanese air defences, however, and a 'ball park' figure is probably about 200 aircraft.

V

Following the end of the war in the Pacific there was an influx of US technical personnel into Japan to examine the state of the art of the enemy technology, in an effort similar to that taking place in Europe. For a full description of the Japanese reaction to the US radio countermeasures, based on these investigations, see Appendix H.

Any consideration of Japanese anti-jamming methods during the war should be seen against the background of severe shortages of research and production capacity, both made more acute by the devastating B-29 raids, coupled with an almost complete separation of the Army and Navy work on radar and anti-jamming systems. Even in the summer of 1945 when the nation was almost at its knees, co-operation between the two services was minimal and there was much useless duplication of effort. And time was not on the side of the Japanese: from the start of the main jamming campaign early in April 1945 only four months elapsed before the war ended. (31)

The Japanese had received details of the German Wuerzlaus anti-Chaff system and the Army conducted some experiments with it. But it was felt that radar operators could track aircraft through Rope clouds (probably they could, so long as supplies of the material to B-29 units remained insufficient) and the counter-countermeasure aroused little interest in Japan. To enable existing radars to operate in the face of electronic jamming, the Army and the Navy each initiated a separate modification programme to enable sets to switch to new frequencies up to 10 MHz above or below those previously used. At the end of the war, however, the Army had got no further than initiating a crash programme to work on this problem; and Navy work had stalled 'due to design difficulties'. (32)

Both services realized the vital need for a searchlight and fire control control radar more modern than the first-generation sets then in use. Great hopes were placed on near-copies of the 560 MHz German Wuerzburg, for which a set of drawings and parts had arrived by submarine in January 1944. The Army version of the radar, the Tachi 24 re-engineered for mass-production in Japan, was to have been built in large numbers by the Sumitomo and Tokyo Shibaura companies. By the end of the war only one Japanese-built prototype of this radar was complete and it did not see operational use. Meanwhile, in a typically wasteful piece of duplication, the Japanese Navy produced its own version of Wuerzburg: the Hama 61, intended as a height finder for the ground control of fighters. In view of the relative ease with which US bombers had been able to neutralize Wuerzburg over Europe, it is difficult to believe that the Tachi 24 or the Hama 61 could have brought the Japanese air defences any lasting relief from jamming. (33)

More realistically, the Navy started work on a version of its 3,000 MHz shipborne Mark II Model 2 radar, for searchlight control.

Had it gone into service this radar might for a time have presented a difficult jamming problem for the B-29's. Countermeasures equipments to cover this part of the spectrum had been developed by the Radio Research Laboratory and prototypes existed; but it would have taken some months to get such equipment into service in quantity. It would not prove necessary: when the war ended only one Mark II Model 2 radar had been adapted for the new role and it was not used operationally. (34)

Both the Army and the Navy appreciated the value of intercept receivers to provide information on the types of enemy radar in use against them. Both initiated programmes to develop such receivers, though their use was not widespread. In addition the Army developed two types of airborne 'wave disturber' (ie jamming transmitter) - the Taki 8 and the Taki 23 - to counter enemy radars operating on frequencies between 40 and 375 MHz. It would seem that by the time these jammers were working the war was in its closing stages, and very few were built. The author has found no record of any deliberate enemy electronic jamming of Allied radars in the Pacific theatre. (35)

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CHAPTER 16 MEANWHILE, BACK IN THE USA . . .

The Harvard Radio Research Laboratory reached its peak strength in July 1944, with a total of about 210 research associates and 600 other personnel (1). Having put into the field equipment to counter almost every type of radar introduced by the Germans and the Japanese, the research teams worked to produce jammers developing yet higher powers and systems to counter possible new enemy radars operating higher in the frequency spectrum.

In parallel with the TDY high power magnetron jammer for the US Navy with an output of 150 watts, RRL developed an airborne equivalent for use against Wuerzburg: the APT-4 Broadloom (150 to 780 MHz). The development of APT-4 was completed in 1944 and it was placed into mass production, but the war ended before it could be used in action (2). To cover the spectrum below APT-4 RRL developed another high powered magnetron jammer, the APT-6 which also developed 150 watts; APT-6 was not quite ready for production when the war ended. (3)

To counter possible new enemy radars operating on frequencies higher in the spectrum, the RRL transmitter section developed two new airborne jammers: the APT-9 and APT-10. The APT-9 was a spot-jammer which used a conventional lighthouse valve as power source and covered the band 1,000 to 2,500 MHz; linked with an associated receiver and panoramic adaptor this was designated the APQ-21. The APT-10 spot-jammer used a tunable magnetron as power source and covered the band 2,230 to 4,030 MHz; linked with an associated receiver based on the APR-5, this was designated the APQ-20 (4). The APQ-20 and APQ-21 were built in small numbers and tested, then held in reserve ready for mass-production if needed to counter enemy microwave radars.

At the end of 1944 US Navy divers salvaged parts of the Mark II Model 2 microwave air and surface warning radar (operating frequency between 2,857 and 3,125 MHz) from a Japanese warship sunk in the Gulf of Leyte (5). The US Navy issued a top priority requirement for a state-of-the-art shipborne microwave jammer and in February 1945 RRL began work on the device, code-named 'Elephant'. Like the airborne APT-10, the shipborne Elephant employed a tunable magnetron as the jamming power source. By the time its operating concept had been finalized, the Elephant had become the most elaborate equipment of its type produced anywhere during World War II. Joe Kearney, one of those involved with it, recalled:

> The Elephant was a most ambitious project for its time, the first-ever attempt at a completely integrated receiving and jamming system on microwave frequencies. Intended for shipboard use, it was a spot jammer covering the band 2,460 to 3,610 MHz and we were to aim at a power output of 1 Kw - one heck of a lot of power on such frequencies at that time. In fact we were able to get only 600 to 700 watts, but that was still very good.
>
> The receiver was not only to pick up the signals from the enemy radar and tune in the jammer, it was also to measure the bearing from the enemy radar. There were to be two transmitter antennas, one at either end of the ship. One of these was trained on the enemy radar, the jamming antenna held on the required bearing by a system of servo amplifiers deriving their information from the ship's main gyros; so even if the ship changed heading, the jamming went out on the same bearing relative to north. (6)

Another important RRL crash programme early in 1945 was the APA-48 homing attachment for use with the APR-1 receiver, which enabled suitably modified Navy F6F Hellcat fighters to home on radar signals from Japanese aircraft. Twenty-five of these homers were hand-built at RRL and the Radiomarine Corporation of America prepared the device for production, but the war ended before it could be used in combat. (7)

During the closing stages of the war RRL personnel were engaged in other countermeasures projects too numerous to be described in detail in this account. Amongst these were the ARQ-11, a 1.5 Kw airborne jammer to counter the guidance systems of enemy guided missiles in the 20 to 70 MHz band (8); various types of air dropped expendable jammer code-named 'Chicks', to counter enemy ground controlled intercept and fire control radars ((9); a range of signal repeaters given the generic code-name 'Peter', to induce directional errors in lobe-switching or conical scanning radars (10); and there were several attempts to produce better intercept receivers. There was continuous development of Chaff, Rope and Angels (corner reflectors), including types for use against microwave radars, and work aimed at improving their efficiency by getting a larger radar echo for a given weight or cost of material (11). The RRL sponsored work on new types of valve and itself developed several specialized types of aerial for countermeasures applications. And for each of the jammers it produced, the RRL designed the associated test equipment to assist maintenance. (12)

In the nature of their work, it was to be expected that RRL engineers would find themselves trying to push the 1940s' technology further than it would go. One example of this was the APQ-14 Moth receiver to enable missiles to home on enemy radars. Three types of winged missile were considered for use for this radar-busting role: the 10-foot span Pelican carrying a 1,000 pound warhead; the 12-foot span Dragon carrying a 3,000 pound warhead; and the huge 36-foot span Glomb (glider bomb) which was to carry a warhead of 4,000 pounds (13). Pelican and Dragon were to be carried under heavy bombers, Glomb was to be towed like a glider. All three of these missiles had originally been designed for use with other types of control - the Glomb, for example, had been tested with radio command guidance and a television camera in the nose to pass back a picture of the scene in front of the missile (14). The RRL tests were not the first with anti-radiation weapons - similar tests in Germany predated them by a few months - but they were certainly amongst the first. Dr John Christensen was one of those involved in this work and recalled some of the difficulties encountered:

> In the anti-radiation role the missiles were intended to attack coastal radar stations and to simulate these we set up a transmitter near the shore at Toms River, New Jersey, for our tests. The initial runs were made with the homing receiver fitted in an aircraft and it seemed to work well enough. But when we put the homing equipment into one of the missiles and began tests with the full system, we found there was a basic problem we had not foreseen. After release the missile came gliding down towards the transmitter accurately enough in the horizontal plane - to within about 100 feet. But the missile antennas picked up quite a strong image of reflection of the transmitted signals off the surface of the sea, which made it appear that the emitter was very much larger than it was. As a result the accuracy of the missile in range was not good enough for it to have

> been effective in action. The work on the anti-radiation missiles continued until the end of the war, without resolving this fundamental problem. (15)

At this time the other organizations associated with the RRL, within Division 15, were also heavily engaged. One very interesting proposal to emerge from the Airborne Instruments Laboratory was a jammer to counter the V 1 flying bomb, with which the Germans were bombarding London during the summer of 1944. This weapon was invulnerable to radio countermeasures in the normal sense of the word: it employed no radar or radio guidance whose signals could be jammed. Azimuth guidance was by means of a magnetic compass controlling a gyro, which operated the rudder via a servo system. Nevertheless even this weapon could have been jammed, as Dr Guy Suits explained to the author:

> The problem was passed to Dr Don Hare and his team at AIL and they figured out a way that was absolutely fantastic. Their idea was to form a magnetic loop employing existing railway lines, suitably interconnected, all the way around London - a circumference of about 60 miles. This loop would be energized with a hefty current to make it into a giant magnetic deflector. They worked out a system which would have required something like 1,000 amps DC, to provide the necessary magnetic field to deflect the compass of a flying bomb at 1,000 feet. The power requirement for the system would have been of the order of 20 to 30 megawatts, which would have meant dedicating quite a large [commercial] power station for this purpose. The system was very seriously considered and design work began on some of the necessary equipment. (16)

While the device was still in the conceptual stage, however, Allied ground troops overran the area in Northern France from which most of the flying bombs were being launched against England. So the idea came to nothing. The jammer to counter the V 1 flying bomb easily holds the record for the most powerful electronic countermeasures equipment ever considered.

One crash programme aimed at meeting a potential threat stemmed from the final German offensive in the west, the 'Battle of the Bulge' at the end of 1944. During the enemy advance a US Army munitions dump had been captured with large numbers of the new radar proximity-fuzed shells. Earlier in the year this weapon had demonstrated its effectiveness against V 1 flying bombs launched against England: it required an average of only 156 shells to knock down a V 1, compared with about 2,800 of the earlier mechanically-fuzed shells (17). Headquarters Army Air Forces became deeply concerned that the Germans might copy the new type of shell and start using it against Allied aircraft. The Research Division of the Aircraft Radio Laboratory at Wright Field was asked to investigate the development of a suitable jammer, calling in RRL assistance if necessary. Lieutenant Jack Bowers, an engineer with the Development Branch at Wright, remembered:

> The proximity fuze had been a closely guarded secret on our side. Even though we had been working on countermeasures for a long time, we at Wright Field had never heard of the device. Now we were asked to investigate, on a crash basis, the possibility of a jammer to counter the fuze. We asked why such a jammer had not been developed earlier, and were told that the developing agency had conducted tests and concluded that the fuze could not be jammed! We worked on the problem, and within two weeks a jammer had been built which would detonate the proximity fuzes prematurely. (18)

The body of the shell served as the aerial for the radar proximity fuze, and this limited the frequency spread of the radar to the band

180 to 220 MHz. The APT-4 high powered jammer covered that part of the spectrum, and was fitted with a motor-driven tuner to sweep the jamming up and down the band used by the fuzes. Modified APT-4's were fitted into a B-17, and a top priority full scale trial using a battery of 90 mm guns was arranged at Eglin to see whether the jamming would be effective. The guns had to fire high explosive shells, because the VT fuze was about 1½ inches longer than the normal mechanical fuze and it could not be fitted into a shell carrying a spotting charge. As a safety measure the guns were to be offset by a small angle, initially 30 mils [about 1.7°] later decreased to 12 mils [about .6°]. One of the jamming operators on the B-17, Lieutenant Ingwald Haugen, remembered:

> It was the sort of test that would never be allowed today, under the prevailing flight safety guidelines. But at the time there was a war on, and the small risk to our one aircraft had to be weighed against the far larger risk to our whole bomber force if the Germans used such a weapon against us. We who were to fly the test were confident we would be all right - we hoped that the jamming would work as planned, and if it didn't the offset fed into the guns would burst the shells at least 240 feet away from us at a range of about 20,000 feet.
>
> The test lasted about 3 months, during which about 1,600 VT shells were fired, individually, in our direction. Sitting in the fuselage of the B-17 the two RCM operators could pick up the radar transmissions from the shells coming up. The VT fuze radiated CW [continuous wave] signals, but the projectiles would often yaw a little in flight and this, in combination with the spin of the shell, would modulate the signal. We in the back could not see out. But the pilots and the navigator would get a kick out of watching the shells burst well below or, if there was a late burst because the jamming had taken some time to sweep through the shell's frequency, it might explode close to our altitude. The general conclusion of the test was that, modified to radiate CW swept across the VT fuze band, the APT-4 jamming could significantly reduce the effectiveness of the proximity fuzed AA shell. (19)

One further aspect of the work of Division 15 that deserves mention is the effort put into the development of anti-jamming devices, to enable US radars to operate in the face of countermeasures (20). The RRL also developed training devices to show the appearance of jamming on the various types of in-service radars. The Laboratory assisted the Army and Navy to produce training films and gave demonstrations to show operators how they could best deal with enemy jamming. As we have seen, neither the Germans nor the Japanese had the development or production capacity to spare for a sustained campaign of this type. And nothing either nation could do was effective against the Allied microwave radars - the introduction of the latter can be considered a successful electronic counter-countermeasure in its own right. For these reasons there was little military demand for counter-countermeasures modifications to radars in operational use. Nevertheless US operators did receive some training in operations in the face of jamming, and the anti-jamming section at RRL maintained a close liaison with the Radiation Laboratory and informed them of the latest jamming techniques.

II

From late in 1944 Division 15, like many of the research organizations set up during the conflict, began to prepare for the end of the war and the need for its services. The Division accepted new projects only where they met a clearly defined need and could be completed within a relatively short time. After the end of the war in Europe there was a further shift in emphasis away from long term projects in favour of short term measures to make the most effective use of existing equipments against Japanese radars. In June 1945 there was an increase in the number of RRL personnel working with the front-line units to increase the usefulness of existing equipment, and had the war continued into 1946 at least half RRL's technical effort would have been employed in this way. (21)

Immediately following the Japanese surrender in August 1945, the RRL Project Committee and the Army and Navy agencies with which it worked reviewed all projects in hand and divided them into three categories: those near to completion or those whose post-war merit was sufficient to warrant their being carried to a conclusion (provided this could be done before 1 November 1945); those whose importance was such that they should be carried on, to the point at which the value of past research would be preserved; and those of no further usefulness which could be dropped. (22)

One of the few projects on which work continued after the end of the war was the Elephant shipborne microwave jammer, as Joe Kearney explained:

> The end of the war brought down the guillotine on the work to develop jammers, with one exception: the US Navy was still very interested in the Elephant project and, since the prototype was completed and ready to be installed in a ship, wanted to conduct sea tests with it. I was only 23 and it was the first position of real responsibility that I have ever been offered. I jumped at the opportunity.
>
> The patrol frigate USS Ashville was made available to us for the Elephant tests. At the Brooklyn Navy Yard the ship's anti-submarine gear was all removed and the jamming equipment installed in its place. Then we took her to Portland, Maine, our base for the sea tests. Ashville was taken up and down the east

> coast, testing out the new "toy" and putting out jamming against ground, shipborne and airborne microwave radars in the area. The Elephant worked beautifully. There was considerable US Navy interest in our activities and we received a continual stream of high powered visitors. (23)

The sea test of Elephant was the last major project undertaken by RRL. Following its conclusion the jammer went to the Naval Research Laboratory. Although it performed successfully the jammer did not go into production: at the time no potentially hostile navy used microwave radar. The jammer was retained as a working prototype, ready to go into production should a threat arise. (24)

By November 1945 the strength of RRL was down to 50 research personnel and 260 other staff, and the numbers of both were falling rapidly. Most of the final work involved the completion of reports on the various projects, with Mike Villard putting together a detailed overall report on the work of the laboratory. The physical plant at RRL, including the office furniture, machine tools, workshop equipment, etc, were turned over to the new Airborne Radio Division of the Naval Research Laboratory. Several projects were transferred en block, with all equipment and documentation, to service research agencies such as the Naval Research Laboratory and the Army's Aircraft Radio Laboratory. The remaining equipment was offered to interested branches of the services and what was left found its way to the surplus market. The closing-down of the other departments of Division 15 moved as rapidly, in similar ways. The final meeting of the Division 15 committee, with Dr Guy Suits in the chair, took place at the Tech-Williams Club in New York on the evening of 6 December 1945. (25)

III

Following the end of World War II and the demise of Division 15 there was a virtual cessation of work on electronic countermeasures in the USA, except for the development of the APR-9 based on the receiver portion of Elephant and a few low priority projects at the Naval Research Laboratory and the Aircraft Radio Laboratory. But the huge wartime effort left a residue which survived the military rundown. There remained moderately large numbers of wartime jammers, receivers and Chaff dispensers, now removed from aircraft and ships and held in store at service depots against a possible future need (the rest of this equipment was sold as government surplus); there was the vast pool of experience in the production, development and use of electronic countermeasures that could again be tapped should the need arise; and, probably most important of all, there was a first-hand awareness amongst members of the fighting services, some of whom would progress to very high rank in the years to follow, that electronic warfare would confer a major advantage in any conflict against a technically advanced nation. The new field of military endeavour, effectively only four years old in the USA in 1946, was not dead. It was only dormant.

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CHAPTER 17 IN RETROSPECT

It is a truism that nothing to do with war is cheap, but some solutions to problems are a good deal more expensive than others. What was the cost of the US radio countermeasures effort during World War II, and what did it achieve?

The Harvard Radio Research Laboratory, which carried out more than three-quarters of the US work to develop radio countermeasures during the conflict, grew from a mere 25 employees in March 1942 to 810 persons of all grades at its peak in the summer of 1944 (1). Between the opening of the laboratory and its closure in February 1946, a period of four years, the laboratory's total budget for wages, running costs, research and model construction was $15 million; an additional $710,000 was spent on the ABL-15 offshoot in England (2). During this 4-year period RRL engineers designed and produced more than 150 separate equipments which drew service orders totalling $242 million; by October 1945 when the remaining contracts were terminated, 427,000 items costing $160 million had been delivered (3). These figures exclude the supply of Chaff and Rope, of which some 30,000 tons were produced at a cost of $39 million. Thus, for each dollar spent on research at the RRL, some 13 dollars worth of equipment were delivered to the US or Allied armed forces. A list of the main countermeasures devices originating from RRL, with details of each and the approximate cost of several of the programs, is given in Appendix C. (4)

In addition the laboratory built, or had built under sub-contract, some 2,800 items of equipment worth $2,680,000 which it turned over to the services for test or experimental use with no transfer of funds (5). In cases where the services had urgent operational needs which could not be met rapidly enough by other means, the laboratory 'crash' produced or arranged for the production of an additional 463 items of equipment costing $2,805,000. (6)

Although initially the US research into radio countermeasures was based on work previously done in Great Britain, it was not long before the Radio Research Laboratory making innovations of its own. The development of high efficiency Chaff and machinery to mass-produce it, the high powered airborne magnetron jammers and the super-high powered ground jammers, are examples of advances which stemmed directly from original US work. In 1945 advanced microwave jammers such as the shipborne Elephant and the airborne APQ-20, then in the testing stage, were a match for state-of-the-art radars then being produced.

The most significant US contribution to countermeasures during World War II, however, stemmed from the harnessing of the nation's huge electronics industry to mass-produce equipment for the Allied forces. Although exact figures are not available on the number of counter-measures equipments produced by other nations, there can be no doubt that during the conflict US production in this field easily outstripped that of all other nations put together; indeed the production of APT-2 Carpet which exceeded seven thousand (7), alone, probably achieved this. When it came to mass production the USA had shown herself in this field, as in others, to be pre-eminent.

In return for all of this effort, what did the US armed forces receive? As we have already seen, it has been estimated that radio countermeasures probably saved about 400 US heavy bombers during operations over Europe; the replacement cost of these aircraft alone was about $150 million at 1944 prices. In the Pacific the use of countermeasures probably saved some 200 B-29 Superfortresses costing a similar amount. These savings in bombers not shot down exceeded the total cost of RRL and the production of the various countermeasures devices. Added to this were numerous other savings and successes made possible by the use of countermeasures: the reduction in the number of aircraft damaged during bombing raids; the continually up-dated picture of the positions and types of enemy radar deployed and their areas of cover, so that operations could be planned to achieve maximum surprise; the sinking of three Japanese submarines on as many nights by the USS Batfish; the US submarines not lost because intercept receivers warned their crews of the presence of enemy ships or aircraft in the vicinity using radar; the delay in any effective German reaction against the Allied ships landing troops on the coast of Normandy on the morning of D-day, 6 June 1944, and a similar slowing of the defences during the many amphibious operations in the Pacific. These are but a few examples, the full list would be considerably longer. And with every such success came a saving in the most precious commodity of all: human lives.

The countermeasures had a not-inconsiderable effect in raising the morale of Allied combat personnel, who could see for themselves the reduced effectiveness of the enemy weapons which resulted; and at the higher command levels there was the reassurance that if the enemy deployed new types of radar or radio-guided weapons, countermeasures could be rapidly implemented. When called upon to do so the Radio Research Laboratory, and the other US agencies developing countermeasures, showed they were able to react within weeks, or even days, to meet new threats as they arose.

As a bonus, the countermeasures effort made the Allied radar designers and service personnel continually aware of the possibility of jamming from the enemy, and the need to make equipment technically and tactically as invulnerable as possible to jamming.

For the enemy forces there was a concomitant reduction in morale at all levels, as the fighting men saw the reduced effectiveness of their own weapons and commanders knew they could do little or nothing to overcome the jamming or reply in kind. The use of countermeasures gave the Allies the powerful advantage of the initiative in the radar war, leaving their opponents to react to events as best they could. The Germans, in particular, were forced to introduce modifications to enable existing radars to continue functioning. This shifted resources away from the development and production of microwave radar, the only real solution to the problem. In Japan there was insufficient time, too few resources and too little co-operation between the services for anything effective to be done to counter the US jamming.

Some readers might be tempted to attribute the success of the US and British countermeasures efforts, compared with those of Germany and Japan, to the different social, military and political systems in the opposing camps. In this writer's opinion the effect of such factors is extremely difficult to prove or disprove. Certainly neither the Germans nor the Japanese were able to deploy their full <u>potential</u> effort in the electronics battle during the conflict, but for the reasons for this we must look elsewhere. In each of the Axis nations the Allied strategic bombing attacks caused delays in the production of electronic equipment which became serious as the war entered its final phase. After 1942 the German electronics industry, like most others in that country, had to give up large numbers of able-bodied men to the armed forces to replace losses at the battle fronts; the poorly trained women and foreign workers that took their places could barely maintain the production of already- proven items of equipment. In Japan there were similar problems, to which must be added the wasteful practice of developing quite separate families of radars for the Army and the Navy. While these factors certainly slowed the reactions of Germany and Japan during the countermeasures battle, the essential question remains: given their relatively small electronics industries and the problems of securing any useful degree of co-operation between them, could any conceivable development and production effort on their part have come near the massive and co-ordinated effort mounted by the USA and Great Britain? In this writer's opinion it could not. In the mass production of countermeasures equipment the huge US electronics industry, unhindered by air attack or any serious shortage of skilled manpower, outproduced by a considerable margin all the other warring nations put together. In the application of science as in most aspects of warfare, God tends to side with the big battalions.

There are other factors to be taken into account. A countermeasures attack cannot be considered in isolation, it has to be related to the military operations of which it is an adjunct. During World War II the most important single application of radar countermeasures was the support of strategic bombing attacks. Relatively little use was made of countermeasures before the beginning of 1942 and a year would elapse before they were being used on a large scale. By that stage of the war only the USA and Britain were able to deploy large forces of heavy bombers and mount powerful strategic bombing attacks. Lacking large forces of heavy bombers, neither the Germans nor the Japanese could have gained much from diverting part of their limited electronic research efforts into countermeasures. In the Axis states scientists were forced to concentrate on keeping defensive radars operational in the face of hostile interference, rather than taking the battle to the enemy. Once it was clear the Axis nations had lost the initiative in the electronics battle, their respective industries were under such pressure that they were unable to close the technological gap that existed between the two sides.

II

Some lessons from the past are absolute and remain applicable to the present day, others do not; wisdom consists in knowing the difference. During World War II it had been relatively easy to jam the German and Japanese radars. But it should be remembered that in every case the victim radars were first-generation sets, designed with little or no knowledge of the types of countermeasure that might be used against them. Initially radars of the same type operated within a very narrow band of frequencies; and even when sets were modified to operate over a wider spread of frequencies, that spread was relatively narrow by today's standards. Another factor which made jamming easier was the sheer scale of the bombing raids during World War II. Attacks by forces of more than 500 bombers were commonplace. The cumulative effect of so many aircraft radiating jamming and dropping Chaff could be devastating to an enemy defensive system employing a few fire control radars operating in relatively narrow parts of the frequency spectrum - even if individual jammers put out little power and Chaff was hand-launched at low rates.

The spiralling cost of modern military aircraft, and the greatly increased effectiveness of their weapons, has seen to it that never again will bombers be used in the numbers employed during World War II. Moreover, penetrating the air defence system of the 1980's is considerably more difficult than that of the 1940's. There are many more types of anti-aircraft weapons system, controlled by numerous different types of radar operating across a huge spread of frequencies and in many cases fitted with complex anti-jamming circuitry and optical back-up systems.

Similar problems face the modern warship in its efforts to avoid attack by homing missiles which can be fired from below the radar horizon. Nevertheless, as in the past, each threatening weapons system can be likened to a chain with at least one link weaker than the rest; and if the chain of weapons control can be broken at any point, even for a relatively short time, an aircraft or ship can survive the engagement.

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Villard, O, Letter to Dr Terman 9 July 1944.

PERSONAL INTERVIEWS

Dr Milton Adams, Mr Jacob Beser, Mr Jack Bowers, Dr Robert Buss, Dr John Christensen, Commander Jack Churchill, Commander Ralph Clark, Sir Robert Cockburn, Mr A. Earl Cullum, Mr John Dyer, Mr Thomas Friedman, Dr Eugene Fubini, Dr Derrick Garrard, Mrs Grace Hagenbuch (nee Horner), Mr William Hagenbuch, Dr George Haller, Colonel Ingwald Haugen, Captain Lawrence Heron USN, Mr William Howe, Colonel Mel Jackson, Dr Richard Johnson, Dr Stanley Kaisel, Mr Joseph Kearney, Mr Vincent Lane, Mr Mathew T. Lebenbaum, Mr Howard Lorenzen, Mr Hugh Lowder, Mr James Magnuson, Mr Carl Miller, Mr Tom Miller, Dr Jerre Noe, Dr Joseph Pettit, Colonel Robert Perry, Mr William Praun, Mr William Rambo, Mr George Rappaport, Dr Richard Raymond, Dr Donald Reynolds, Lt Cdr Douglas Roberts, Dr Win Salisbury, Dr Don Sinclair, Dr Les Slote, Dr Robert Soderman, Colonel Harry Smith, Mr Edwin Speakman, Mr J. Greg Stephenson, Dr C. Guy Suits, Professor Frederick E. Terman, MR Edward Tietz, Herr Fritz Trenkle, Commander Donald Vaughan, Dr O. G. 'Mike' Villard, Colonel Joseph Wack, Colonel Hugh Winter, Colonel Frank Wintry.

GLOSSARY OF TERMS

ABL-15. American-British Laboratory of Division 15, US countermeasures laboratory at Malvern, England.

AI. Airborne interception (radar).

AIL. Airborne Instruments Laboratory. During the early part of the war this laboratory was part of NRDC Division 6 engaged in research into anti-submarine devices. At the end of 1943 became part of Division 15. After the war became an independent company working on aircraft electronic systems, including countermeasures.

A/J. Anti-jamming.

Angels. Generic code-name for radar corner reflectors used to deceive enemy radar.

ASV. Air to surface vessel (radar).

Band Designation Letters (World War II):

P Band - 200 to 390 MHz

L Band - 390 to 1,650 MHz

S Band - 1,650 to 5,200 MHz

X Band - 5,200 to 11,900 MHz

Big Ben. Allied code-name of the German V 2 bombardment rocket.

Black Cats. Nickname for US Navy PBY Catalina flying boats and amphibians which usually operated at night in the Pacific theatre. These took part in Elint work on several occasions.

Broadloom. Code-name for the APT-4 jammer.

Carpet. Code-name for the APT-2, APT-5 and APQ-9 series of equipments to jam radars in the 560 MHz band.

CAST MIKE PROJECT 1. Code-name given to the team undertaking the initial US Navy Elint operations in the south Pacific area.

Chaff. Metal foil cut to approximately half the wavelength of the radar to be jammed.

Chain Home. British early warning radar.

D/F. Direction finding (by radio or radar means).

Dina. Code-name for the APT-1 jammer.

Division 15. Division of the World War II US National Defense Research Committee, responsible for work on electronic countermeasures.

DRAGOON. Code-name for the Allied invasion of Southern France in August 1944.

Dueppel. German code-name for Chaff.

Egerland. German microwave Flak control radar system.

Elephant. US Navy shipborne microwave jammer, under development when the war ended.

Elephant Cigar. Code name for the MRT-1 VHF high powered ground communications jammer.

Elint. Electronic intelligence.

EW. Early warning (radar).

Ferret. Aircraft fitted with intercept receiving equipment, to search for enemy radars.

Flak. German abbreviation for Fliegerabwehrkanonen - anti-aircraft guns.

Freya. German early warning radar.

Fritz-X. German radio controlled guided bomb.

FuGe 16. German VHF airborne communications transceiver.

GCI. Ground controlled interception (radar).

GEE. British hyperbolic navigation device, carried by some US aircraft.

Giman-shi (deceiving paper). Japanese code-name for Chaff.

GLIMMER. Code-name for the feint attack against the Boulogne area, mounted in support of the invasion of Northern France on the night of 5-6 June 1944.

H2S. British ground mapping radar, carried by some US aircraft.

H2X. US ground mapping radar.

Henschel 293. German radio controlled glider bomb.

HUSKY. Code-name for the invasion of Sicily.

IFF. Identification Friend or Foe, radar transponder equipment.

Jackal. Generic code-name for US airborne communications jammer.

Kettenhund. German airborne jamming equipment, for use against radars in the 200 MHz band.

LCGL. Landing Craft, Gun, Large. Landing craft sometimes fitted with radar jammers to cover landings.

LCIG. Landing Craft, Infantry, Gun. Comments as above.

LCTA. Landing Craft, Tank, Attack. Comments as above.

Lichtenstein BC. German airborne interception radar.

Mammut. German early warning radar.

Mandrel. Generic code-name for US and British jammers against radars in the 125 MHz band, including the APT-3.

Mannheim. German searchlight and Flak control radar.

Moonshine. Generic code-name for the Allied radar repeater jammers.

Nuernburg. Code-name for German modification to the Wuerzburg radar, to give some relief from the effects of Chaff jamming.

NRL. Naval Research Laboratory.

OVERLORD. Code-name for the Allied invasion of Northern France in June 1944.

Oboe. British ground controlled bombing device, carried by some US aircraft.

P-540. General Radio Company designation of the prototype equipment which formed the basis for the SCR-587, APR-1 and APR-4 family of intercept receivers.

Perfectos. Generic code-name for device to trigger the German FuGe 25 IFF equipment, and enable Allied fighters to home on the reply signals.

Porcupine. B-29 dedicated to the radar jamming role.

Radiation Laboratory (sometimes shortened to Radlab). US centre for research into radar during World War II, operating under the MIT at Cambridge Massachusetts.

Raven. US nickname for electronic countermeasures equipment, and electronic countermeasures operators.

RRL. Radio Research Laboratory, Harvard; centre for the development of US radio countermeasures equipment during World War II.

Rope. Code-name for long untuned lengths of metal foil dropped from aircraft to jam low frequency radars.

Rotterdam. German code-name for H2S bombing radar carried by Allied aircraft.

Rug. Code-name for the APQ-2 jammer.

SCR-268. US searchlight and fire control radar.

SCR-270. US early warning radar.

SCR-271. US early warning radar.

SCR-545. US microwave fire control radar.

SCR-584. US microwave fire control radar.

SCR-587. US airborne intercept receiver.

Seetakt. German naval surface search and fire control radar.

SLC. Searchlight control (radar).

Tachi. Generic term for Japanese Army ground radars.

Taki. Generic term for Japanese Army airborne radars and jammers.

Tase. Generic term for Japanese Army shipborne radars.

TITANIC. Code-name for the fake airborne invasion mounted in support of the invasion of Northern France on the night of 5-6 June 1944.

TAXABLE. Code-name for the feint attack against the Le Havre area, mounted in support of the invasion of Northern France on the night of 5-6 June 1944.

TDY. US Navy high powered shipborne jamming equipment.

Tuba. Code-name for the MPQ-1 high powered ground radar jammer.

VT (variable time). Proximity fuse.

Wassermann. German early warning radar.

Window. Original British code-name for reflective devices such as Chaff and Rope; sometimes this code-name was also used in the USA.

Wismar. Code-name for the modification of the Wuerzburg radar, to enable its operating frequency to be shifted to avoid electronic jamming.

Wuerzburg. German searchlight and Flak control radar.

Wuerzlaus. Code-name for a modification of the Wuerzburg radar, to provide some relief from Chaff jamming.

XARD. Designation of an early intercept receiver produced by the Naval Research Laboratory.

APPENDIX A

Original recommendation from the National Defense Research Committee, in January 1942, which led in the following month to the establishment of the Radio Research Laboratory at the Massachusetts Institute of Technology, Cambridge, Massachusetts.

NATIONAL DEFENSE RESEARCH COMMITTEE

Microwave Section D-1

Proposal No. 030642 - B

Subject: ESTABLISHMENT OF RADAR COUNTER-MEASURE LABORATORY

It is recommended to the NDRC that a contract be entered into with the Massachusetts Institute of Technology for the ESTABLISHMENT OF A RADAR COUNTER-MEASURE LABORATORY. The sum of this contract is not to exceed $300,000.

Recently, at the insistence of the Navy, a program on Radar Countermeasures has been started under the leadership of Professor F.E. Terman of Stanford University. In order to get this project under way and to take advantage of the organizational background of the Radiation Laboratory, this project has been started at the Massachusetts Institute of Technology.

Since it is desirable to separate from the Radiation Laboratory as many related activities as can be advantageously carried out in other places, and also, since the Radar Counter-Measures program is substantially different in character and in the interest of secrecy should be separate from the Radiation Laboratory, the Radar Counter-Measure project should be set up as a separate and distinct organization and its early removal from the framework of the Radiation Laboratory is to be encouraged. The Massachusetts Institute of Technology has indicated its willingness to handle the Radar CounterMeasure project as a separate unit with the expectation that it will later be transferred completely to another contractor.

Contractor:	Massachusetts Institute of Technology, Cambridge Massachusetts.
Letter of Intention to be sent to:	Mr N.M. Sage, Mass. Inst. of Tech. Cambridge, Massachusetts
Origin of Project:	Navy, through Admiral J. A. Furer
Official Investigator:	Dr F.E. Terman
Project Discussed By:	NDRC: Dr K.T. Compton, Dr A.L. Loomis Prof. E.L. Bowles
	Navy: Admiral J.A. Furer, Comm. L.V. Barkner
	Rad. Lab.: Dr F.E. Terman, Dr L.A. DuBridge
Effective Date:	January 1, 1942
Terminating Date:	June 20, 1942
Performance and Reports:	To establish a laboratory for research and development in the field of radar counter-measures, to supply apparatus to the Services, to assist in operational studies, and to report from time to time as requested.
Amount:	$300,000.
Classification:	Secret

APPENDIX B

Letter dated February 16 1942, from Karl T. Compton of the National Defense Research Committee to Dr Frederick E. Terman, confirming the latter's appointment as Director of the US radio countermeasures laboratory. This step marked the beginning of efforts to develop this form of warfare in the USA.

SECRET

NATIONAL DEFENSE RESEARCH COMMITTEE

of the Council of National Defense

1530 P Street NW

Washington D.C.

February 16, 1942

Dr. Frederick E. Terman

Radiation Laboratory

Dear Dr. Terman:

This letter is to confirm, on behalf of the N.D.R.C., your appointment as Director of the R.C.M. project which is being set up under Section D-1, and to set forth certain understandings in regard to the development of this new project.

It is understood that the R.C.M. project initially will be set up as part of the Radiation Laboratory and will operate for the present as a separate and distinct project under the general policies and within the structure of the Radiation Laboratory. For various reasons, however, it is desirable that this project should be administratively separate from the Radiation laboratory as soon as possible, after which time the R.C.M. project and the Radiation Laboratory will be parallel activities, each under a director, both reporting to Section D-1. In this stage the connection between R.C.M. and the Radiation laboratories will be through Section D-1 at the top and through informal personal cooperation down the line.

N.R.D.C. believes, as a matter of general policy, that undue concentration of its activities in any one institution should be avoided unless there are sound reasons of efficiency in such concentration. Consequently it is my hope that the sponsorship of the R.C.M. project can later be transferred from M.I.T to some other institution, preferably Harvard in order that the easy working relationships with the Radiation Laboratory can be maintained. I would not recommend transference of this project away from this locality unless this should meet with your approval as director of the project. But even before possible transfer to the sponsorship of another institution, I believe that the administration of the R.C.M. project should be established as a separate entity as soon as this can be worked out between yourself for N.D.R.C. and Mr Sage representing the contractor. Until this can be done, however, the R.C.M. group can use the purchasing and personnel organization of the Radiation Laboratory.

It is understood that as director of the R.C.M. project you will assume the following responsibilities and authorities:

1. To recruit the necessary personnel for an adequate organization to conduct this project. Some of the initial members of your organization may be, by mutual consent, furnished by the Radiation Laboratory, but

you are authorized to secure additional personnel from outside the Laboratory, following in general the personnel and salary arrangements which are in force in the Radiation Laboratory, with such changes which seem to be necessary in particular cases as are agreed upon between yourself, Dr F.W. Loomis, and the DIC office at M.I.T.

2. To make the necessary arrangements, in consultation with Dr. A.J. Allen, for preparing, occupying and equipping space in the Hood Building in which the laboratory will operate for the present.

3. To purchase, at first through the Radiation Laboratory and M.I.T. purchasing organizations, such permanent equipment for the Laboratory and such apparatus and supplies as are required for carrying on this work.

4. To authorize travel orders for yourself, and such others of your organization as you designate, to make necessary trips for purposes of recruiting, consulting with Army and Navy officers and industrial companies in regard to the program of your Laboratory.

It is furthermore understood that you will be willing to take full responsibility for planning, organizing and directing the work connected with this project. The objective of the R.C.M. project I think has been made clear to you in general terms. The general policies under which the project operates are laid down by the Microwave Committee, Section D-1, and you are designated as their agent to execute these policies. It will be your responsibility to determine the size of the organization required to carry out these general plans and to recommend to Section D-1 the appropriation of the funds which you estimate will be required. You understand also, that the Massachusetts Institute of Technology as contractor with the N.D.R.C. is responsible for the general operation of the Radiation Laboratory and your Laboratory, and that both laboratories operate under administrative procedures set up by M.I.T.

It is impossible at the present time to outline the scope and size of the R.C.M. project. The Microwave Committee has agreed, at the request of the Army and Navy, to undertake an intensive program on this subject. The particular lines of attack to be undertaken, however, will have to be outlined by your own organization, in consultation with the armed services, Microwave Committee and Radiation Laboratory members. It is anticipated that this project will be a very important one, and that during the next six or eight months it will have reached a status of employing 50 to 75 individuals. No definite budget for this project can yet be set up but you will be asked to submit budget estimates as soon as these can be made to cover the work in the immediately forseeable future.

The many administrative matters connected with the scientific program and the organization of this project cannot be outlined in writing, but must be worked out as they arise, in collaboration with and consultation with the Director of the Radiation Laboratory, the Chairman of the Microwave Section, Dr. Alfred Loomis, and with the President and other Administrative officers of M.I.T., all of whom will collaborate with you to the fullest extent to make possible the greatest possible success of this very urgent and important project.

In conclusion I would emphasize the ultra-secret character of this project. The work of the Radiation Laboratory itself is very importantly in the secret category, but the R.C.M. project is of such character that even greater care should be taken, not only to prevent any disclosure of information, but even to prevent every unnecessary intimation that work of this sort is in progress. Only by such care can the collaboration of the armed services and of our allies be secured and can the risk be avoided of losing the benefits of our effort.

Very sincerely yours

Karl T. Compton (signed)

APPENDIX C

DETAILS, PRODUCTION AND COSTS OF THE MAIN COUNTERMEASURES EQUIPMENTS DEVELOPED BY THE RADIO RESEARCH LABORATORY

Sources: RRL Transition Department Final Reported dated 1 December 1945; and the Summary Technical Report of Division 15 NRDC.

Note: Unless otherwise stated, the numbers and prices are those of the production versions of the equipments; unit prices are averaged over the total production run.

1. JAMMERS.

APT-1 'Dina'. Airborne jamming transmitter covering the 90 to 220 MHz band, power output 12 watts. Production: RRL 7; Delco Radio Division 6,195. Cost $8.8 m ($1,430 each).

SPT-1. Shipborne version of the APT-1. Production: Delco Radio Division 50.

APT-2 'Carpet'. Airborne jamming transmitter covering the 450 to 720 MHz band, power output 5 watts. Production: Delco Radio Division 6,270; Hudson American Corp 1,000. Cost $2.9 m ($400 each).

SPT-2. Shipborne version of the APT-2. Production: Delco Radio Division 400.

APT-3 'Mandrel'. Airborne jamming transmitter covering the 85 to 135 MHz band, power output 10 watts. Production: Delco Radio Division 1,105. Cost $2.5m ($2,200 each).

SPT-3 Shipborne version of the APT-3. Production: Delco Radio Division 60.

APT-4 'Broadloom' High powered magnetron airborne jamming transmitter covering the 150 to 780 MHz band, power output 150 watts. Production: General Electric Co 2,092; Stromberg Carlson Co 100. Cost $6.57m ($3,000 each).

TDY. Shipborne version of the APT-4, initially covered the band 350 to 800 MHz band (later modified to jam to a lower frequency limit of 116 MHz; some modified to jam to an upper frequency of about 3,000 MHz), power output 150 watts. Production: General Electric Co 1,538. Cost $7.8 m ($5,700 each.)

APT-5 'Carpet IV' Airborne jamming transmitter covering the 350 to 1200 MHz band, power output 15 watts. Production: Aireon Mfg Co 4,100; Delco Radio Division 2,663. Cost $6.5m ($968 each).

SPT-6 Naval version of the APT-5. Production: Aireon Mfg Co 81.

APQ-2 'Rug'. Airborne jamming transmitter covering the 450 to 720 MHz band, power output 5 watts. Could be modified to extend the lower frequency to 150 MHz. Production: Delco Radio Division 8,265. Cost $4m ($4,650 each).

SPT-4. Shipborne version of the APQ-2. Production: Delco Radio Division 719.

APQ-9. 'Carpet III' Airborne jamming transmitter covering the 475 to 585 MHz band, power output 20 watts. Production: Delco Radio Division 9,279; Hudson American Corp 5,174. Cost $7.97m ($551 each).

SPT-5. Shipborne version of the APQ-9. Production: Delco Radio Division 240.

APQ-20. Airborne jamming system covering the 2,300 to 4,200 MHz band, power output 10 watts. System included the APT-10 transmitter, APR-5A receiver and a panoramic adaptor. Production: Belmont Radio Corp 56, built under a crash programme at a cost of $746,000 ($13,300 each).

ARQ-8. 'Dina', or 'Dinamate' Airborne jamming transmitter covering the 25 to 100 MHz band, power output 30 watts. Production: RRL 50; Hallicrafters 1,210. Cost $2.16m ($1,714 each).

MPQ-1 'Tuba'. Ground jamming transmitter covering the 480 to 500 MHz band, power output 25 Kw, two such transmitters per site. Production: RRL 1; Delta Star 2. Cost $1.9 m ($.6m ea).

RECEIVERS AND ATTACHMENTS

APR-1. Radar intercept receiver fitted with a range of tuning units. Initial coverage 100 to 950 MHz; final coverage 40 to 3,300 MHz band. Production: Galvin Mfg Co 2,571; figure includes the SPR-1, the shipborne version.

APR-2. Automatically recording intercept receiver covering the 90 to 1,000 MHz band. Production: Galvin Mfg Co 325.

APR-4. Radar intercept receiver, version of APR-1 for Army Air Forces manufactured by Crosley Corp. Frequency coverage as for APR-1. Production: Crosley Corp 4,356.

APR-5 and APR-5A. APR-5 was a radar intercept receiver covering the 1,000 to 3,100 MHz band. APR-5A was similar, but modified to give a frequency coverage of 3,000 to 6,000 MHz. Production: Galvin Mfg Co 3,432; figure includes the SPR-2, the shipborne version.

APR-7. Radar intercept receiver covering the 1,000 to 3,500 MHz band. Production: RRL 25; Union Electronics Co 100.

APA-17. Airborne broadband direction finder 250 to 1000 MHz. Production: Hoffman Radio Corp 888; Aviola 557.

AS-186/APA-17. Microwave direction finding attachment for APA-17, 1000 to 5000 MHz. Production: Craig Machine Works 1,025.

APA-23. Paper tape recording device for use with APR-1 and APR-4 receivers. Production: Gamewell Co 1,496.

APA-24. 'Setter' Direction finder 100 to 750 MHz for use with intercept receivers. Production: Heyer Products 310.

APA-42. Direction finder 60 to 750 MHz. Production: RRL 17; Lear Inc 40.

APA-48. Homing system Navy F6F Hellcat fighter, to enable the aircraft to home on radar emissions from enemy aircraft. Production: RRL 25

CHAFF, ROPE AND ASSOCIATED EQUIPMENT

OCA-2. 18" Chaff cutter. Production: International Paper Box & Machinery Co 444.

OCA-3. 12" Chaff cutter. Production: International Paper Box & Machinery Co 87.

A-1. Automatic airborne dispenser for Chaff or Rope, using taped bundles. Production: Airmetal Products Co 12,705; Dayton Acme Co

A-2. Automatic airborne dispenser for Chaff or Rope, for carriage by fighters. Production: Prosperity Inc 1,620.

Chaff (Main Types):

CHA-2. Paper backed bent Chaff (347 to 404 MHz). Production: Reynolds Metal Co 1.14m pounds.

CHA-3. Paper backed bent Chaff (510 to 595 MHz). Production: Reynolds Metal Co 2.16 m pounds.

CHA-25. Embossed bent Chaff (320 to 600 MHz). Production: Aluminum Co of America 1.027 m pounds; Standard Rolling Mills 27,000 pounds.

CHA-28. Paper backed bent Chaff (450 to 600 MHz). Production: Reynolds Metal Co .3 m pounds; Standard Rolling Mills .1 m pounds.

CHA-28 (RR-4/U). Embossed bent Chaff (450 to 600 MHz). Production: Reynolds Metal Co 3.795 m pounds; Johnston Tinfoil Co 1.415 m pounds; Standard Rolling Mills .22 m pounds.

RR-4/U-T. As above, but bundles taped for use from automatic dispensers. Production: Reynolds Metal Co 2.44 m pounds; Standard Rolling Mills 1.18 m pounds.

CHB-0. Paper backed flat Chaff (110 to 116 MHz). Standard Rolling Mills .296 m pounds; Reynolds Metal Co .246 m pounds; Johnston Tinfoil Co 21,200 pounds.

Untuned Rope:

CHR-1 (RR-2/U). Each bundle contained three rolls of foil, each 400 feet long with a small parachute to hold it vertical in the sky after deployment. Production: Standard Rolling Mills 2.46m pounds.

CHR-2 (RR-3/U). Foil content as for CHR-1, but with 3-in square card instead of a parachute. Production: Reynolds Metal Co 1.46 m pounds; Johnston Tinfoil Co 1.32 m pounds; Standard Rolling Mills .13 m pounds.

RR-3/U-T. As above, but bundles taped for use from automatic dispensers. Production: Standard Rolling Mills 2.9 m pounds; Reynolds Metal Co .16 m pounds.

APPENDIX D

NOTE ON THE OPERATION OF HEAVY ANTI AIRCRAFT GUNS DURING WORLD WAR II

During World War II the victim radars for most of the US jamming were the German and Japanese sets used to control fire from heavy anti-aircraft gun batteries. Some readers may not be familiar with World War II anti-aircraft fire control methods, and for an understanding of their vulnerability to jamming this Appendix is included.

World War II anti-aircraft (AA) guns can be divided into two main categories: heavy AA, single-shot weapons of calibre 75 mm or greater, aimed using predictors to engage targets at medium or high altitude; and light AA, automatic firing weapons of calibre 40 mm and smaller, aimed using direct sighting optical methods to engage targets at low altitude. Neither the Germans nor the Japanese attempted to use radar fire control for light AA guns, and this type of fire will not be considered further.

Heavy AA weapons, of 88 mm, 105 mm and 128 mm calibre in the case of the German guns, or 75, 88 and 120 mm calibre in the case of the Japanese, for the most part fired high explosive time-fused shells which burst at previously set distances from the gun. Usually a battery of heavy guns comprised four, six or eight weapons and a basic fire control system comprising a predictor and an optical rangefinder. Using range and bearing information from the range finder, the predictor continually calculated where the target aircraft <u>would be</u> when the shells reached it.

Taking as an example an aircraft flying at 20,000 feet at a slant range of 5½ miles, an 88 mm shell would take about 19 seconds to cover this distance; and in this time a B-17 at 225 mph would fly just over a mile. So for an accurate engagement, at the time of firing the gun barrels had to be aligned on a point in the sky more than a mile in front of the aircraft. The predictor calculated this lead distance and converted it into a continually varying series of settings, which it passed by electrical pointers to the crewmen laying the guns in azimuth and elevation. The predictor also calculated the time-of-flight of the shell, which it passed to the gun loaders who set the shell's clockwork fuse to detonate at the correct range (the proximity fused shells used by the Allied during the final year of the war did not require this setting, but neither the Germans nor the Japanese were able to bring this type of shell into service). Firing was usually by salvoes, with all guns engaging the same target aircraft. When engaging a formation, it was the usual practise to aim at the lead aircraft.

For night engagements using the basic fire control system, an aircraft at medium or high altitude had to be illuminated by searchlights so that the range-finder crew could track it. Precision radars, such as the German Wuerzburg and Mannheim or the Japanese Tachi 1, 2, 3, 31 and Mark IV Models 1, 2 or 3 could be used to set searchlights on to targets. Or, at night or if the target was above cloud, these radars could provide tracking information on the target which was fed into the predictor and thence to the guns. Thus any interference of the control radars would render impossible accurate predicted fire against targets above cloud; and it seriously reduced the chances of a successful engagement at night even if the skies were clear.

When their searchlight and fire control radars were jammed, both the Germans and the Japanese made attempts to use acoustic locators to track aircraft at night or above cloud. But because it was limited by the relatively low speed of sound, this method was virtually ineffective against aircraft flying at more than 200 mph or above 10,000 feet: at a range of 6,000 yards the sound of an aircraft's engine noises took 18 seconds to reach the locator, which meant that the resultant bearing information was invariably well out of date.

If predicted fire was not possible gunners could resort to barrage fire; i.e. aiming their weapons at a designated point in the sky through which it was calculated the enemy bombers would have to fly to reach their bomb-release point. In terms of the number of aircraft brought down this method used vast quantities of ammunition, however, and neither German nor Japanese gunners were permitted to make large-scale use of it.

APPENDIX E

THE DEVELOPMENT OF RADAR IN GERMANY, TO THE END OF WORLD WAR II

Sources: Die deutschen Funkmessverfahren bis 1945 by F. Trenkle.
'Intelligence Information on RCM Effectiveness in the ETO'

German work on the development of radar began in earnest in 1933 when Dr Rudolph Kuehnold, head of the Naval signals research department, initiated research in this field. By October the following year a continuous wave radar operating on 600 MHz, built by the GEMA company, was detecting ships at ranges of up to 7 miles. German work on radar proceeded independently of similar work taking place in other nations and during 1935 tests with an improved radar, employing pulsed transmissions and fitted to the tests ship Welle, gave ranges of 5 miles on other ships and 12 miles on coastlines. In the spring of 1936 GEMA built a 150 MHz pulsed radar able to detect aircraft 30 miles away; with some alterations this became the Freya operating on 125 MHz, the first German early warning radar to go into production. The Navy received the first production Freyas early in 1938.

Following its success with Freya GEMA produced the 375 MHz Seetakt, a surface search and gunnery control radar; one of these was on board the heavy cruiser Graf Spee when she intervened in the Spanish Civil War in the summer of 1938. Meanwhile the Telefunken company had also begun work on a mobile 560 MHz radar for the control of anti-aircraft guns; this performed successfully during tests and the Luftwaffe ordered it into large-scale production.

At the outbreak of World War II, in September 1939, the Luftwaffe and the Navy had in operation about a hundred Freyas. In the summer of 1940 the A-Model Wuerzburg entered service with the Luftwaffe; as well as providing fire control information for guns this set was used to direct searchlights, for early experiments in the control of night fighters and as a height finder at the more important Freya sites.

In the two years that followed there was a steady expansion of the German radar network, as more and more sets became available and improved models went into production. At this time the sets deployed in the greatest numbers were the Freya for air early warning, and the Naval Seetakt at coastal sites and on warships; both were soon overtaken in numbers by the Wuerzburg, however, as production of this set went ahead with the intention of providing sufficient for one for each flak battery.

During this period the only attacks mounted against the German homeland were by the Royal Air Force night bombers, and most of the improvements to radars were aimed at increasing their effectiveness to counter this threat. For early warning the Mammut and Wassermann radars were introduced, developed from Freya and operating on similar frequencies but with more powerful transmitters and larger antenna reflectors to extend their range. The Mammut, built by the I.G. Farben company, employed a fixed antenna 90 feet wide and 35 feet high - about the size of a tennis court - and was the world's first phased-array radar to go into service; in azimuth its beam was swung electronically to 50° either side of the normal, in front of the array. The GEMA development of Freya, code named Wassermann, featured an antenna array 130 feet high, rotated for azimuth scanning and employing electronic vertical scanning for height finding.

At the same time there were improvements to the Wuerzburg. The C-model, with lobe-switching to improve alignment accuracy, followed the A-model into production. Then in the autumn of 1941 the D-model went into production, featuring 25 Hz conical scanning aligned manually, to improve accuracy further; the Wuerzburg D would be built in large numbers and remained numerically the most important German fire control radar until the end of the war. To provide a low-risk precision radar of increased range for the close control of night fighters, Telefunken produced the Giant Wuerzburg (Wuerzburg Riese); this set was electrically similar to the Wuerzburg D but featured a dish-shaped reflector with more than twice the diameter (26 feet instead of 10 feet) to increase the maximum range from 25 miles to 40 miles.

Telefunken also produced an airborne interception radar for night fighters, the 490 MHz Lichtenstein. For maritime search GEMA produced the 120 MHz Rostock and the Flugfunkforschunginstitut developed the 180 MHz Neptun; these were built in only small numbers, however, and the main airborne surface search radar was the 550 MHz Hohentwiel from Lorenz which appeared at the end of 1942. A modification of Neptun saw much greater use fitted to many types of combat aircraft as a tail-warning radar.

The opening of the US strategic bombing offensive in Europe, in the summer of 1942, imposed no new demands on the German radar system. Day bombers attacking in clear skies were far easier for fighters to intercept and flak to engage than night bombers, and the systems designed to counter the latter could easily cope with the former.

During 1943 Telefunken placed in production the slightly more powerful Mannheim radar operating on the same frequencies as Wuerzburg, and intended to replace the earlier set. Mannheim provided a smoother and more accurate flow of fire control data and had several interesting features including aided manual tracking, dual meter/scope presentation and, in a few versions, automatic tracking.

By the autumn of 1943 the US and British jamming offensives were in full swing, with the entire range of German air defense radars experiencing both Chaff and electronic jamming. In the case of the Lichtenstein airborne interception radar and the Giant Wuerzburg when used for night fighter control, the effects of Chaff proved so severe that neither set could continue in use in its original role. To replace the Lichtenstein the entirely new 90 MHz SN-2 radar was hastily introduced for night fighters; and because the Giant Wuerzburg was no longer effective for the purpose, the Luftwaffe abandoned close control for night fighters and instead resorted to loose control methods. A few Giant Wuerzburgs were relegated to use as flak control radars, and served in this role at some of the more important targets.

For the other German radars there was a steady stream of modifications, with the introduction of new frequencies to avoid electronic jamming and various types of moving target indicator to avoid the effects of Chaff (several of the anti-jamming systems are listed with the technical details of the various radars at the end of this Appendix.)

Meanwhile, the Mannheim radar had started to replace the Wuerzburg at many flak batteries. But when confronted by Chaff and electronic jamming the new set proved just as vulnerable as its predecessor, and the high priority accorded to the production of Mannheim was dropped.

Two interesting developments of previous radars entered service in 1944: the Jagdschloss and the Giant Wuerzburg-Gustav. The Jagdschloss was yet another radar based on the Freya, but with a greater power and fitted - for the first time in a German production set - with a plan position indicator presentation. Jagdschloss was the most important ground controlled interception radar during the closing months of the conflict. The Giant Wuerzburg-Gustav was a normal Giant Wuerzburg, to which had been added the components of a Freya radar whose antennas used the same dish. Thus if there was jamming on the Wuerzburg frequencies, the Giant Wuerzburg could get an approximate bearing on the jamming and the Freya could obtain range readings. This set was used for the control of flak batteries at some of the more important targets.

The real solution to the jamming problem was to introduce a range of entirely new microwave radars, and the Germans had been intent on doing this since they had captured an almost-intact example of the British 3,300 MHz H2S bombing radar early in 1943. Due to the steady stream of crash programmes to replace or modify earlier radars to operate in the face of jamming, however, it was not until the end of 1944 that the first German microwave radar system began operational tests: the Egerland developed by Telefunken in conjunction with the Luftwaffe proving station at Werneuchen. The Egerland system comprised two separate radars: the Kulmbach search radar operating in the 3,450 to 3,615 MHz band, which provided target acquisition; and the Marbach operating in the 3,245 to 3,315 MHz band, which tracked targets and provided the fire control data. One complete Egerland station was used operationally, from a site at Schuandorf near Berlin, from January 1945. In this installation the Kulmbach and Marbach operators controlled their radars from an underground operating room. When the war ended no further Egerland stations had entered service.

DETAILS OF THE MAIN TYPES OF GERMAN GROUND RADAR

Note: Because all of these radars ran to numerous sub-types, the technical details given should be regarded as representative for the type only.

Freya Early Warning Radar

Quantity built 1,000 plus — Peak power 15 - 20 Kw

First used 1938 — Pulse Length 3 microsecs

Maximum search range about 100 miles — PRF 500

Frequencies used: 120 - 130 MHz (originally)

57 - 187 MHz (by the end of the war)

Anti-jamming systems fitted:

The only system fitted was Freya-laus, a doppler-detection system to filter out the echoes from Rope.

Seetakt Surface Vessel Reporting and Gun Ranging Radar

Quantity built about 200 — Peak power 8 Kw

First used 1938 — Pulse Length 3 microsecs

Maximum range: against ships, depended on site. — PRF 500

Frequencies used: 368 - 390 MHz

Mammut Early Warning Radar

This radar employed a fixed antenna, with electronic scanning.

Quantity built about 20 — Peak power 200 Kw

First used 1942 PRF 500

Maximum search range up to 185 miles

Frequencies used: 120 - 130 MHz (originally)

120 - 150 MHz (by the end of the war)

Anti-jamming systems fitted:

As for Freya.

Wassermann Early Warning Radar

This radar employed a normal rotating antenna for azimuth scanning, and used electronic scanning for height finding.

Quantity built about 150 Peak power 100 Kw

First used 1942 PRF 500

Maximum search range up to 175 miles

Frequencies used: 120 - 130 MHz (originally)

119 - 156 MHz (by the end of the war)

Anti-jamming systems fitted:

Wasserfloh, similar to the Freya-laus, fitted to some sets. One version of this radar, the M2, could be re-tuned rapidly to any other frequency within the coverage of the radar to avoid jamming.

Jagdschloss Ground Controlled Interception Radar

This search radar was the first German set to go into production using the plan position indicator method of presentation.

Quantity built 80 Peak power 150 Kw

First used 1944 Pulse length 1 microsec

Maximum search range up to 112 miles PRF 500

Frequencies used: 129 to 165 MHz.

Anti-jamming systems fitted: no specific systems, but the radar was able to switch rapidly to unjammed frequencies.

Wuerzburg Model D Flak and Searchlight Control Radar

Quantity built 3,000 to 4,000 Peak power 7 - 11 Kw

First used 1940 Pulse Length 2 microsecs

Maximum search range 25 miles PRF 3,750

Maximum tracking range 15 miles, using 25 Hz conical scan

Frequencies used:

A Band, 553 - 566 MHz (initial operating band)

B Band, 517 - 529 MHz (introduced in Autumn of 1943)

C Band, 440 - 470 MHz (introduced at end of 1944)

Anti-jamming systems fitted:

The Wuerzburg D was the most-used German flak control radar during World War II, and the main victim of the US jamming. For this reason the radar was modified to employ a greater range of anti-jamming systems than any other. The list given below is not comprehensive:

Stendal — Modification to permit direction-finding on jamming signals. In practice accuracy was poor, and little tactical use was made of this device.

Wuerzlaus — Introduced in the Autumn of 1943, to counter the effects of Chaff. This was a coherent

	pulse system, claimed to be able to track aircraft through Chaff echoes three times the amplitude of the aircraft echo.
Nuernberg	Introduced in the Autumn of 1943. This system enabled aircraft to be tracked through Chaff, using the propeller modulation.
Taunus	Introduced in the Autumn of 1943. Used a short time constant video filter, to improve the ability of the radar to track targets through weak concentrations of Chaff.
Wismar	Fitted to all sets from the summer of 1944, to enable them to switch frequencies rapidly between bands.
Tastlaus	Had replaced Wuerzlaus on most radars by the early part of 1945. Used an improved coherent pulse system, to allow the Wismar system and the 'laus' method to be used simultaneously.
Eidechse	This was a frequency changing technique, to allow the direct frequency shift within given bands.
Urechse	This modification made possible the frequency shift between Wuerzburg band and all intervening frequencies. Thus BC Urechse provided frequency shift from the high end of the B band to the low end of the C band.

ABC Urechse allowed continuous frequency shift over the entire Wuerzburg spectrum.

K-laus — Intended for fitting to most sets, only about 125 had received it by the end of the war. This modification made use of range-strobing and band-pass video filtering of doppler frequencies to afford good separation of doppler frequencies. Claimed to enable aircraft to be tracked through Chaff echoes of 15 to 20 times their amplitude.

Mannheim Flak and Searchlight Control Radar

Quantity built 400 plus	Peak power 15 - 20 Kw
First used mid-1943	Pulse length 1.4 microsecs
Maximum search range 19 miles	PRF 3,570

Maximum tracking range 12.5 miles, using 25 Hz conical scan.

Frequencies used:

A,B and C Bands as for Wuerzburg.

Anti-jamming systems fitted:

Wuerzlaus, Wismar, Tastlaus, Eidechse and/or K-laus fitted to most sets. Also Windlaus, installed in a few sets in the Spring of 1944; this was an auxiliary to Tastlaus, which permitted the operator to balance out particular doppler frequencies coinciding with the wind motion of Chaff.

Giant Wuerzburg. Originally used for the control of night fighters, about 50 were in use at the end of the war for flak control at the more important targets.

Quantity built about 1,500	Peak power 7 - 11 Kw
First used 1941	Pulse length 2 microsecs
Maximum search range 37 miles	PRF 1,875

Maximum tracking range 22 miles, using 25 Hz conical scan.

Frequencies used:

A and B Bands as for Wuerzburg.

Anti-jamming systems fitted:

Several of the systems used with Wuerzburg.

Giant Wuerzburg-Gustav Flak Control Radar

This was a combination of the normal Giant Wuerzburg (Wuerzburg Riese) and a Freya. The Freya components were mounted on the Giant Wuerzburg, and the Freya antennas were fitted to the Wuerzburg reflector dish. The Freya was used as an aid to setting the Giant Wuerzburg on to targets, and it could also provide range information when the latter was jammed.

Quantity built: modification fitted to nearly all Giant Wuerzburgs used for flak control. Details below relate to Freya attachment.

First used 1944	Peak power 15 - 20 Kw
Maximum search range: 95 miles	Pulse length 2 microsecs
Frequencies used: 136 - 187 MHz	PRF 500

Egerland Microwave Flak Control System.

Only one complete system built, began operational tests at the beginning of 1945. This system comprised two separate radars, the Kulmbach search radar for target acquisition and the Marbach for target tracking.

Kulmbach

Maximum search range 31 miles	Peak power 20 Kw
Frequencies used:	Pulse length .6 microsecs
3,450 - 3,615 MHz	PRF 1,500

Marbach

Maximum search range 15 miles	Peak power 20 Kw
Frequencies used:	Pulse length .6 microsecs
3,243 - 3,315 MHz	PRF 1,500

APPENDIX F

THE EFFECTIVENESS OF US RADIO COUNTERMEASURES IN THE EUROPEAN THEATRE OF OPERATIONS

Note: this Appendix is extracted from the lengthy and definitive post-war report 'Intelligence Information on RCM Effectiveness in the ETO', prepared by ABL-15 and dated 16 June 1945.

Indications of Effectiveness from German Sources

A quantitative indication of the extent to which our jamming impaired German Flak operation is very difficult to obtain. The difficulty is exemplified by the reaction of many German PW's who, when asked to give a quantitative figure, quietly threw up their hands. A number of factors enter into any estimate which attempts to be quantitative, some of the more important being the personal characteristics of the individual making the estimate, the directness of the information the individual has at hand, the vast differences in operational conditions at various locations, the changes in RCM and radar operations and equipment as a function of time, and the tendencies of an individual to remember the extreme case rather than the typical encounters. In view of all these possibilities of uncertainty it is surprising that relatively consistent estimates have been obtained from many divergent German sources. In general, it appears that an overall impairment of radar controlled Flak to approximately 25% of its normal effectiveness resulted from the combined use of Window and Carpet jamming. This means that in cases where weather conditions during daylight operations made radar tracking necessary, USAAF jamming allowed the Germans to operate only to one-fourth of their capabilities for Flak defense.

The importance of this reduction is emphasized when it is realized that on a yearly average, approximately 40% of the 8th Air Force missions in the ETO were under conditions of 8/10 - 10/10 cloud, essentially blind operating conditions. In the period 1st September to 31st December 1944, 50% of all missions from the UK encountered over 8/10 cloud, 35% encountering 10/10 cloud over target areas. If the statements that Flak is only 25% effective when radar control must be used in the presence of jamming, and that weather conditions force radar control to be used 40% of the time, can be accepted, then it appears that jamming caused the overall, all weather, Flak effectiveness to be reduced to 70% of normal. These figures, however, must not be taken at face value, but rather as an indication of the fact that RCM was effective. To enable the reader to draw independent conclusions, it is desirable to present the actual statements and information obtained from German Generals, engineers, radar officers, radar technicians, radar operators, and from published reports, which led to such figures.

In reading these statements, it is important to understand that several different points of view are involved. Some of the estimates refer to the reduction in radar tracking ability resulting from our jamming. Others are based on the person's understanding of the reduction in Flak effectiveness, and are thus comparisons between good radar directed fire and whatever substitute fire is employed. In all cases, the recollections are based on operations during recent strong USAAF jamming. The increase in our Window jamming strength from its beginning was duly felt by the Germans and the very great increase in Carpet jamming in Fall '44 was considered a severe blow. Carpet jamming had not been entirely effective before that date. Thus, the following statements are based on German experience after our combined Window and Carpet jamming program realized its full strength, since November - December 1944. Also, they are restricted in all cases to consideration of only US daylight operations. RAF jamming of Wuerzburgs had not been considered quite as serious a matter as USAAF practices; several Germans having emphasized this point. The RAF tactics were such that saturation (electric) jamming was never possible. RAF Window, of course, caused a great amount of interference, but alone it could more frequently be handled by the radar operators.

(1) Radar Operators' Opinions - Fifteen operators of Wuerzburg D radar from North, Central and Southern parts of Western Germany were asked on what percent of their attempted radar tracks in the presence of combined Window and electronic jamming were they able to track successfully. Replies ranged from that of five operators who replied "none of the time", to one estimate of 80% of the time. Only two estimates exceeded 50%. By zones, the average estimates ran: North, 27%; Central, 34%; South, 30%. When all replies were averaged, including the extreme values cited, it was found that tracking, under the conditions stated, was possible 30% of the time.

The same questions put to three Mannheim operators brought forth replies of 0, 20%, 40%, averaging 20%.

Nine operators of Wuerzburg Riese's [Giant Wuerzburgs] gave answers which averaged to 41%. From this, it might be tentatively concluded that though it did certainly suffer from jamming, the Riese was somewhat more effective than the Wuerzburg D against jamming. Because of this difference and because of the small scale use of Riese, this figure is not included in the overall average.

(2) Radar Technical Sergeants - Two Technical Sergeants interrogated had worked at various operational sites and in addition had put in considerable time on experimental work at the German Air Force station at Heiligensee/Berlin. To quote a translated statement written jointly by these two men, "Approximately 90% of the radar sets employed during jamming had to fall out during constant jamming even though at first they were able to track. Completely jammed targets could not be tracked." From this it may be inferred that the Flak control radar was, on the average, only 10% effective when jamming was present.

(3) Comments from Two Wuerzburg D Technicians - Two experienced technicians stated that they had experienced combined Window and electric jamming, and had found it possible to track successfully using Nuernberg and Wismar techniques during 30% of the time.

(4) Comment of a Mannheim Technician - This PW stated that "the combination of Window and radio jamming is the most successful Allied radar countermeasure." He stated further that he tracked the target successfully 25% of the time in the face of Window and radio jamming. As pointed out elsewhere in this report, the jamming susceptibilities of Wuerzburg D and Mannheim radars were commensurate.

(5) Opinion of Flak Generals - Generals Giese, Von Rantzau, and Roemer jointly made a statement to the effect that German radar attained roughly 30% of the standard attained before we began to jam.

(6) Comment by a Radar Officer - A Leutnant Whisken, radar Officer for the Hamburg area, indicated that Window had very severely hampered radar Flak control even before the introduction of electric jammers. He further explained that the presence of electric jammers had made radar fire control even more difficult, and he estimated that since early 1945 the Germans had been able to get only 10% effectiveness from their radar as a result of jamming.

(7) Information Published by Luftwaffe - In the 12th Supplement to "Summary of Previous Enemy Jamming of German Ground and Airborne Radar," dated 2-7-45 (included in EIS - 12/45), a chart was included on which day-to-day records for the month of January 1945 show the percentage of Flak radars, in areas flown over by US bombers, which encountered jamming. If one could justify considering these jammed radars to have been

rendered ineffective, a figure of 27% effectiveness in the presence of jamming would be obtained.

(8) Comment by German Scientist - Dr Elbe on the staff of the BHF [Government agency formed for the development of microwave radar techniques] and one of the leaders of A/J research in Germany, when interrogated on the effectiveness of Allied daylight jamming, replied "In general the probability of hits, when a large amount of Window is used, is reduced by a factor of 5." This statement, based only on Window jamming, would infer that even here only 20% effectiveness was realized with radar Flak control.

(9) Comment by an Air Force Technical Advisor on Radar Problems - On the subject of US jamming Professor Mueller, in charge of technical liaison between the research organizations and the Air Force, made the following statement, "The Allied combination of Window and electronic jamming was very effective." In answer to a question of how much the jamming reduced the effectiveness of Flak, Professor Mueller made it clear that this was a very difficult question to answer, but he thought that the effectiveness of Flak was reduced to 33% of that obtained when no jamming was present on non-visual fire. This figure takes into account the difference between radar-controlled predicted fire effectiveness and barrage fire effectiveness as it was used in certain parts of the Reich.

(10) Comment by German Scientist - Dr Hueter, who worked on A/J devices at the Ernst Lecher Institut, thought that our noise

jamming was very effective and in most cases sufficient by itself to completely jam practically all the radars. In December 1944, he had made a trip to several of the best Flak radar sites in Germany in order to become acquainted with the operational jamming problems. He estimates that from his experience, the probability of hits was reduced by a factor of 5. Dr Plendl, who was in charge of the German high frequency research effort in 1943, also shared this opinion.

(11) Comment by German General - Generalleutnant Veith, commander of the Flak School Division, estimated the efficiency of optically controlled Flak as compared with radar controlled Flak as three to one. As reasons for this difference, he included human errors from involvement of a larger number of persons, more complicated data transmission path, and disturbances of radar data. One cannot take the 33 per cent figure as completely attributable to jamming in this case, although from other statements by the same General one can justify charging a large portion of the loss in effectiveness to the jamming. The General was thinking in terms of overall performance when the figure was given.

These statements are so arranged that numbers 1 through 7 are based on estimates of radar impairment whereas numbers 8 through 11 deal with estimates of overall Flak impairment. Taking unweighted averages of these two groups of comments, a figure of 22 per cent effectiveness if obtained for radar tracking capability and of 26.5 per cent for Flak effectiveness. The difference in these figures might be taken as a measure of the partial effectiveness of the barrage Flak fire substituted for predicted fire when the radar was jammed. However, the extent of the data available is by no means sufficient to support such a conclusion. The only figure which can be justified is that roughly 25 per cent effectiveness was realized by German Flak defenses when strong jamming was encountered.

An additional source of information from which references can be drawn as to jamming effectiveness is the available data on the number of rounds of Flak fire required to shoot down our aircraft. The General Von Rantzau mentioned earlier stated that for the 88 millimeter guns around Berlin, 800 rounds per kill was considered a good fire record against US heavy formations. This was stated as the average for parts of January and February of 1945 "when conditions were favorable." In unfavorable periods the average would go down to something of the order of 3,000 rounds per kill. Use of barrage fire under blind conditions was made necessary by jamming and was stated as the principal factor entering into this reduction of effectiveness. Taking the ratio between the barrage and the predicted firing figures, it appears that the effectiveness was reduced to 26.7 per cent largely as a result of jamming.

The close resemblance of this figure to that obtained by averaging the estimates of Flak impairment is interesting but does not mean anything further than an additional check on orders of magnitude. Taking the radar impairment figure to 22 per cent, the Flak impairment estimates of 26.5 per cent and the rounds per kill figures of 26.7 per cent, one can derive only one pertinent conclusion: the alternative means of Flak firing used when radar control was jammed was so ineffective as to make reduction in radar effectiveness almost synonymous with the reduction in Flak effectiveness . . .

An indirect indication of the effect of jamming on German radar Flak-control may be found in the changes ordered in firing procedure at various times. Before jamming became serious the procedure was, of course, to use radar control whenever visual or visual-radar control was not possible. Strenuous efforts were made to operate the radars through the jamming and to obtain at least some measure of fire control. To a certain extent these measures were successful, but as our Window and eventually Carpet jamming became stronger during 1944, orders were given to Flak batteries to fire so-called predicted-barrage when complet-ely controlled fire was impossible. Extensive installations and procedures were evolved at important target areas such as Berlin and Hamburg for limited control of barrage fire from the Flak Division Headquarters. Batteries fired on the basis of prescribed altitudes and grid-square locations, such information being based on general location data supplied by the Jagd [fighter] Division in the area. Wuerzburg Riese and Riese G sets were used to supply additional data for use in this procedure. Similar methods were used at nearly all target areas. None of the German defense personnel had a high opinion of this procedure and it was truly an interim proposition. Although it was generally inefficient and wasteful of ammunition, it was used for several reasons:

a. To make US aircrews think that countermeasures were ineffective and to possibly bring about abandonment of jamming.

b. To maintain the morale of both the civil and military population of the target area by providing the same sound effects that would pertain to clear-weather defenses.

c. To get at least some advantage from lucky hits.

To a certain extent the first point was accomplished. Oberst [Colonel] Hentz cited a particular raid where the controlled barrage was used at Berlin. The consensus among the Germans was that the activity had been most ineffective. However, Hentz interrogated several crew-men from downed Eighth Air Force planes and found that these men were under the impression that the Flak had been very accurate and that their countermeasures had failed them. Of course, such firing practice did not fulfill the intended function of Flak, and it became extremely costly in ammunition at a time when ammunition and transportation were becoming critical items. Thus, between October and December of 1944 the practice was gradually restricted until, during most of 1945, barrage firing was employed only at the target areas which the Germans considered of highest importance for either military or political reasons.

Further qualitative indications of the effects of our jamming have been obtained from various P/W's of all ranks. The general impression is that practically everyone connected with Flak in Germany, regardless of his particular job, was well aware of the existence and general effectiveness of the jamming. In some Commands it has been found that the jamming and the stories about its effectiveness which circulated among the personnel of the Command had so undermined the trust of the Commanding officers in radar, that they were extremely adverse to any usage of radar fire direction equipment.

General agreement has been found among Germans that the combination of Window and electric jamming was particularly effective. For example General Veith, Head of the Flak Artillery School Division of the Flakwaffe, made the following statement "Jamming became really serious after October 1944 . . . Chaff gave some trouble commencing in the autumn of 1943, but these difficulties had to a certain extent been overcome . . . as a result of active (electric) jamming, radar at times became completely useless, and in such cases (when firing was conducted under non-visual conditions) Flak did not go into action at all as the practice of barrage firing had been given up."

Further testimony as to the value of combined Window and electric jamming was offered by Flak Officer General Giese who stated that "Active jamming alone would not have been successful, since some German radars would soon hit upon a frequency not jammed. Window killed this possibility" . . .

In the face of these various statements as to the effectiveness of our jamming, it is well to mention that our countermeasures were sometimes not effective. Many cases cited in German Battle Reports indicate that a certain number of Flak radars would be able to track through even very strong jamming. Conditions such as siting, luck in picking a good frequency, wind conditions (as regards effects of Window motion on the "laus" devices), relative location and flight path of the attacking formations all entered into such occurrences. During most of 1944 such individual AJ successes were common. After strong jamming began, particular cases of tracking by a few radars still occurred. This is a natural conclusion when it is realized that radar control of Flak was able to achieve an overall effectiveness of ¼ of normal.

A detailed study of such Battle Reports would lead to a more factual evaluation of jamming effectiveness than is attempted herein. However, it is felt that the Germans' overall estimates are a sufficiently good source of information for this report. Thus, from the German prisoners' opinions and recollections of statistics, it can be seen that jamming of Flak control radar by our Eighth Air Force and Fifteenth Air Force raids over Germany was decidedly effective. Jamming bothered the Germans from its first use, but as they developed circuitmeasures and operating techniques, a particular type of jamming would be more easily countered, though never completely. However, it appears from the various comments and estimates, that after late 1944, our combined Carpet and Window jamming became so severe as to succeed in reducing their blind-Flak effectiveness to the order of one-quarter of normal. The Germans' situation was not comfortable and can best be summed up by the statement of General Giese "From the summer of 1943 on, it was no fun being a German AA officer."

German Anti-Jamming Measures

As is true in all types of warfare, the jamming war consisted of a series of attacks and counterattacks. Introduction of new types of jamming and new tactics by the Allies constituted the attacks and the development and application of various anti-jamming measures by the Germans formed the counter-attacks. In the following pages, a brief history and description of the technical warfare between the German Flak control radars and the jamming efforts of the USAAF is presented.

From the very beginning of the war, the Germans feared the possible effects of Allied jamming of their radar. In 1940 they first investigated the possibilities of using Window for jamming, and found its potential effectiveness so great that they discontinued the investigation and kept all information on it very secret in fear of possible use against them if the Allies found out about it, but never considered developing AJ measures for it for defensive use.

The capture of the Wuerzburg at Bruneval in 1942 caused a considerable amount of concern in military circles and General Martini, Chief of radar for the Air Force, called a conference with representatives from the military, research and industrial organizations to discuss the matter (the Air Force was responsible for the Flak defenses in the German military organization). It appears that their main concern was over the possibility of electronic jamming of the Wuerzburgs by the Allies and no consideration was given to the possibility of Window jamming. The decision reached was that the best countermeasure for any

Allied electronic jamming would be the spreading of the Wuerzburgs over a wide frequency band. Telefunken was given the task of developing such a system. Flak Artillery School III at Heiligen See later made some tests of the effect of electronic jamming using a modulated Lorenz 40L transmitter as a jammer and developed the Stendal procedure.

In January 1943 small scale tests of Window jamming were conducted . . . but the secrecy was still kept very high and "Ostrich" tactics were continued. Window was given the code name "Dueppel", but it was not allowed to appear in print.

In spite of their previous work, the Germans were totally surprised and unprepared when the RAF first dropped Window on Hamburg in July 1943. In fact Prof. Scherzer, who was later second in command of the BFH, said that General Martini telephoned him at 2 am on the night of the raid to tell him how the British had dropped Dueppel and had completely jammed their radar. He wanted to know what could be done to overcome it . . .

When the shock due to the beginning of Window jamming wore off, the effectiveness of the radars against the Window jamming increased somewhat as the operators did not give up when they saw Window echoes on the screen but tried to plot through them. However, this was not successful most of the time as the Window jamming was too strong and the jamming did result in an appreciable reduction in the effectiveness of radar Flak control.

A very high priority was assigned to the development of anti-jamming devices for Window and a large number of scientists and engineers were put to work on the problem. Attempts at solutions were made using the following principles:

(1) Propeller modulation.

(2) Doppler effect.

(3) Special CRO screens to distinguish moving targets from non-moving ones.

The first device developed was the Wuerzlaus, which was invented by Dr Fach and Dr Moeller of the Max Wien Institut, within two weeks after the first Window raid. This modification operated on the coherent-pulse doppler principle and under ideal conditions made it possible to track an aircraft whose echo was 1/3 the amplitude of the reflection of the Window cloud. However, a considerable amount of skill was required to use it effectively and keep it tuned up properly, and also its effectiveness decreased rapidly with the movement of the Window by the wind.

Taunus and Nuernberg devices were produced next. Taunus was intended to clear much of the Window clutter from the CRO screen by removing the low frequency components. Nuernberg originally was designed as a device working on propeller modulation which would enable the radar to obtain accurate fire control data. However, it was unsuccessful in this respect, but was used as an auxiliary to Wuerzlaus to keep the radar approximately tracking targets when the window was too dense for successful operation of Wuerzlaus. In this way, it was possible to take advantage of any holes in the Window cloud for obtaining accurate fire control data using Wuerzlaus.

Within three months of the first use of Window, 60 per cent of all Wuerzburgs were equipped with Wuerzlaus, Taunus and Nuernberg. A large scale operator training program was initiated as the effectiveness of the AJ devices against Window was very largely dependent on the skill of the operator. Motion pictures were made on jamming and anti-jamming, training manuals were published, practice raids were flown dropping Window, and a staff of instructors was obtained and trained. However, practically all of the operator training was done in the field under adverse conditions and as a result the success of the program was far from complete. Also around the end of 1943, drafting of young men from the Flak defenses started and resulted in a continuous decrease in the number of intelligent and experienced operators. However, in spite of this fact, the effectiveness of the radars against Window jamming gradually increased as a result of Wuerzlaus and the training program.

The commencement of electronic jamming of the Wuerzburgs in October 1943 by the USAAF, and in February 1944 by the RAF, caused the Germans a considerable amount of concern. Immediately, plans were made for spreading out the Wuerzburgs over a wider frequency band and for the development of techniques for shifting frequency rapidly. The effectiveness of the electronic jamming as first carried out by the USAAF was probably not very great as the barrage was quite thin and no

Window was used. However, when the USAAF also commenced dropping Window in December 1943, the combination of the two appeared to have been very successful in preventing the Germans from obtaining accurate radar fire-control information.

The deployment of the Mannheim Flak radar in the field started in late 1943 and by December, 120 were operational at high priority targets. However, according to practically all the interrogated Germans, there was practically no difference between the Mannheim and the Small Wuerzburg in their susceptibility to both Window and Carpet jamming, and therefore no distinction will be made between them in the following discussion. Practically all of the AJ devices were applied to both Wuerzburgs and Mannheims, but in most cases it was much more difficult to adapt an AJ device to the Mannheim than to the Wuerzburg. Thus, in general, the application of the various AJ devices to Mannheims lagged the Wuerzburgs by several months.

Countermeasures against electronic jamming were introduced in the field early in 1944 and consisted of modifications of Wuerzburgs to shift frequency within certain bands during operations (Wismar) and for operation in either the old A band or the new B band. In this connection, the broad band dipole was also introduced in the field. By March 1944, a large number of modifications had been completed.

At this time Wuerzburg radars in the field were equipped with several types of transmitter and local oscillator units which had different tuning ranges. The older models operated only at fixed frequencies in A band; newer models operated in either A or B band, but either used two complete interchangeable transmitter-local oscillator units or used one unit which required the services of the maintenance crew to shift in frequency. The newest models could be tuned rapidly to any frequency inside of either band by the operators but required the services of a mechanic for shifting bands. In the newest type of unit, A and B, it was possible to shift frequency during an attack if the radar was jammed, and resume tracking of the formation quickly enough to permit firing by the batteries. In fact, with practice, it appears from interrogation of operators that an average crew was able to shift frequency within a band in slightly less than a minute and between bands in about four minutes. The German operators claim that the shift to B band was very effective for a short period of time, but soon this band became partially jammed.

One factor which limited the effectiveness of Wismar was that when it was used during operations against electronic jamming, Wuerzlaus could not be used against Window as the tuning adjustments required in shifting the frequency of the coherent oscillator used in Wurzlaus were very delicate and required too much time to complete. Hence a considerable sacrifice in the effectiveness of the radar in the presence of Window jamming resulted when Wismar was used.

In order to overcome this difficulty, the development of another type of a pulse doppler unit called Tastlaus, which did not need to be tuned when the radar frequency was changed, was started. However, this device was not completed until late in the year . . .

By the summer of 1944, the Germans apparently were beginning to be able to cope with Window jamming and Carpet jamming fairly effectively as the amount of electronic jamming was decreasing and the operators were becoming experienced in working against Window. However, the Germans claimed that in the summer the Window dropped began to increase appreciably, and it continued to increase until the quantities dropped were so great that even Wuerzlaus was ineffective most of the time. At this time more pressure was placed on the development of anti-Window devices to enable radars to work effectively through these heavy clouds.

On top of this increase in the quality of Window jamming, the sudden increase in the amount of electronic jamming in October 1944 caught the Germans entirely by surprise and proved to be very effective. All of the scientists, engineers and military personnel agreed that the most effective means of jamming was the combined use of Window and Carpet, and that the tactics employed by the USAAF were very effective in jamming their Wuerzburg radars. Prof. Scherzer of the BHF and others said that only two solutions were advanced which were not long-range projects. One was the extended spreading of the frequency coverage, and the other was the increasing of the transmitter power. Development was started on both ideas. Plans were made for the design and production of modifications which would permit operation in the C band and for the development of a 1 megawatt Wuerzburg. The first plan was carried out but the second was not completed by the end of the war. Also, a very large number of personnel were employed in longer-range problems for solving this problem.

The only immediate measure that was at all effective was the use of Wismar. Tastlaus was introduced into the field in quantity in November and contributed somewhat toward the freeing of the radars from jamming, but in general it appears that both the electronic and Window jamming were too strong for either Wismar or Tastlaus to be very effective.

When it was possible for the operators to find a hole in the jamming, it was usually possible to track the target long enough before it was jammed to obtain enough information for firing. As an average it took the operators about one minute to shift frequency within bands and about four minutes to shift from one band to another. They also thought that on an average they were able to track for about three minutes before they were jammed again.

The Stendal procedure had been tried earlier against electronic jamming, and had not proven to be successful probably due to the very poor accuracy resulting and to the circular polarization of the jamming after our use of the Fishhook antenna beginning in summer-fall 1944.

The pinpointing of a formation carrying a jammer by D/Fing on it with two radars was tried but was unsuccessful due to the uncertainty as to which formation each radar was observing.

The Wuerzburg Riese or Giant was used in limited quantities for Flak control. The set was originally designed for GCI [ground controlled interception] operation but its use for Flak control was begun at about the time that our jamming began. Due to its immobility, it was usually used only at important targets where a fixed location was justified. Late in the fall of 1944, the Riese-Gustav attachment was installed, providing the Riese with a built-in Freya radar. The original function of Gustav was to facilitate setting on-target for actual tracking with the Riese and was intended for GCI service . . . There was indication of some usage of the Riese-Gustav to supply range and, by D/F on jamming, directional information to Division Headquarters for the predicted barrage firing plans. The Riese-Gustav was slightly more effective against jamming than the Wuerzburg D for the following reasons:

(1) The narrower beam width reduced the Window echo slightly and also reduced the area in which jammers would be effective.

(2) The Freya components were useful in setting the Wuerzburgs on.

(3) In the presence of electronic jamming, the Freya section could obtain the range and approximately keep the Wuerzburg set on the formation when it was jammed, thus enabling the operators to make more effective use of Nuernberg (accurate angular data was not obtainable from the Freya as no split was used).

In general the Gustav was slightly more effective in overcoming jamming than Small Wuerzburg, but the improvement was not very great . . .

The area-controlled or "predicted" barrage fire described previously was used as an interim firing procedure in cases where the Flak radars were thoroughly jammed. This was an attempt to get firing data for all batteries from whatever radars in the area were free from jamming. Thus, in the Berlin area, Jagdschloss, Freya, Wassermann, Farstuhl Freya and by chance a few unjammed Rieses, Mannheims, and Wuerzburgs were used as sources for data, the firing instructions for all batteries were given from Division Headquarters on the basis of a combination of all this data. In a sense, the tactic was a grandiose scheme for utilizing widely spread radar frequencies but, of course, the firing data being given only as grid-square and altitude, was so inaccurate as to make the system a poor substitute for tracked firing. The Germans realized this limitation but felt the procedure was the best that could be evolved under the circumstances.

In the winter of 1944, a new anti-Window device called the K-laus was developed which made it possible to track aircraft when the ratio of the Window echo to the aircraft echo was between 15 and 20 to 1. Several experimental sets were installed in December 1944. Late January, 1945, approximately 40 or 50 were operational, and orders were placed for 1,000 more. This device was very susceptible to electronic jamming and Wismar had to be used first to find a hole in the electronic jamming. However, it was certainly very effective against Window alone, and against Window and Carpet when it was possible to find a hole.

According to Oberst Hentz, in operational tests at Hannover around the first of the year, two batteries equipped with this device scored 12 kills in a two-month period, which was phenomenal as two normal batteries usually did not score any kills in that length of time. He also thought that most of the victories occurred at night as the electronic jamming was less intense then, and it was easier to find a hole.

At the end of 1944 two modifications for use in the Wismar procedure were introduced which were called Urechse and Eidechse. Urechse was a device which permitted tuning of the radar over A, B and C bands and all frequencies between these bands. Eidechse was a similar device, but permitted operation only within the A, B and C bands. These devices were designed to allow further spreading of the Wuerzburgs to C band and to frequencies between B and C bands in order to get away from electronic jamming (C band covers approximately 440 to 470 Mc). Urechse, however, had a serious defect in that it was equipped to work with Wuerzlaus and not Tastlaus, and hence was difficult to tune rapidly if Wuerzlaus was not used. Eidechse, however, was equipped with Tastlaus which made it easier to tune, but it did not cover the frequencies between bands. Around the first of the year the Wuerzburgs started to operate in C band as it was found that the jamming was much less effective there. Here again, the Germans tried to hide the C band and gave strict instructions:

(1) Not to operate radars in the C band unless absolutely necessary.

(2) Not to track single aircraft or small formations that might be radar reconnaissance aircraft.

(3) To operate during a raid for the shortest possible time.

In January 1945, about 100 or 4 per cent of the GL [gunlaying] radars were operating on C band according to both German and Eighth AAF spot-jamming records. Oberst Hentz stated that plans had been made for rapidly shifting a large number of sets to C band, but he did not know how many had been equipped for C band operation by the end of the war. Eighth Air Force search logs showed about 25 per cent of the Wuerzburgs operating in C band in March.

The Germans claimed that only a small amount of electronic jamming was encountered in this band although the Window jamming was still effective. As a result, the radars were able to track targets a much larger per cent of the time.

One trick which was once tried at Hamburg in an attempt to fool our spot-jamming operators, was to arrange the frequencies of the radars in such a manner around the target that there was an outer ring operating in A band, an inner ring operating on B band and a central ring operating on C band. The plan was to turn on the sets on A band first to draw our spot-jammers on them, then turn on the B band sets to snare the remainder, and finally turn on the C band sets which they hoped would be unjammed and hence would be able to supply accurate tracking information to their respective batteries. This was said to be unsuccessful as all of the spot operators were not fooled, and a proper account had not been taken of our barrage cover of the A and B bands.

At the end of January the first 9 centimeter GL set, Egerland, was used operationally. The Germans claimed that this equipment operated very satisfactorily and were well pleased with it. Another Egerland was completed, but its whereabouts is unknown. One thousand Egerlands were on order and 100 were scheduled for delivery in 1944 but the Allied bombing had delayed production.

All of the Germans felt that one of the most important reasons that their anti-jamming program was not more successful was the continual lowering of the level of intelligence and experience of the Flak radar personnel. Many of the experienced operators had been drafted into the infantry and their replacements were old men or girls who were rushed through a brief training course and sent into the field. All of the technical personnel interrogated felt that a good operator could do a lot to overcome the effects of jamming; but good operators were very scarce. Many comments were made to the effect that the various AJ devices required a very good operator to make them work.

The German scientists felt that by early in 1945 they had solved the Window problem as they were convinced they had devices in use or in development which would render Window jamming ineffective ... However, they had no practical solution for noise jamming except operations on the centimeter band, and they felt that in time they would have the same trouble with this band and hence were working frantically to find a solution to the overall problem.

APPENDIX G

THE DEVELOPMENT OF RADAR IN JAPAN, TO THE END OF WORLD WAR II

Sources: US official report 'A Short Survey of Japanese Radar' by the Operations Analysis Section and the Air Technical Intelligence Group of the Far East Air Force, dated 20 November 1945.
Royal Air Force Signal Intelligence Report 'Japanese Radar Equipment, 30 November 1944.

Note: only the more important radars are described in the account which follows.

The development of radar in Japan dates from 1936, when Professor K. Okabe at the University of Osaka began work on an electronic method of detecting aircraft. Working under the famous Dr Yagi (who gave his name to the Yagi aerial), Okabe concentrated on the development of a bistatic system with a separated transmitter and receiver, to detecte the interference to radio signals caused when an aircraft passed between the two. The method of operation was, therefore, the same as that tried at the US Naval Research Laboratory in the 1920's and early 1930's but which had already been overtaken by pulsed systems. Unlike the work in the US, however, the Japanese were to continue the development of the interference detector in parallel with that of pulsed radars. To differentiate between the two systems the Japanese refered to the interference detector as the Type A equipment and the pulsed radar as the Type B. Okabe saw the great advantage of the Type A equipment to be that, compared with a pulsed system, for a given transmitted power far greater detection ranges could be achieved. Since low transmitter power was to dog the Japanese radar program throughout the conflict, this was an important consideration. The great drawback of the interference detector was that did not give the position of the aircraft along the line between the transmitter and the receiver, and despite much hard work the Japanese team was never able to resolve this fundamental problem. After a lot of experimentation the Type A system went into production in 1940, operating in the 40 to 80 MHz band and using transmitters developing between 3 and 400 watts. During 1941 the Type A entered service with the Japanese Army and was deployed in quite large numbers; in all about a hundred of these equipments were built and they remained in service until the end of the war. The longest Type A line of detection was from Formosa to Shanghai, a distance of more than 400 miles.

Japanese work on the development of pulsed radar began in 1941, with completely separate programs by the Army and the Navy which resulted in a considerable waste of effort to produce different radars of similar (and, compared with those of the Allies low) performance. Because of their separate lines of development, the Army and the Navy programs will be described separately in this account.

The Japanese Army radars followed a fairly logical designation system. Each equipment had a type number preceded by Tachi meaning land-based ('chi' from tsuchi meaning 'earth'), Tase meaning ship-borne ('se' from misui meaning 'water') or Taki meaning air-borne ('ki' from kuki meaning 'air'); in each case the type designation was prefixed 'Ta' from 'Tama Institute', the Army's research institute near Tokyo.

The first Army radar to go into production was the Tachi-6 static early warning set which operated on frequencies in the 68 to 80 MHz band. Thus unusual radar employed a transmitter with an omni-directional or wide-angle aerial, and three or four separate receivers each with rotatable directional aerials to search for echoes from targets (in more recent times this same principle, lobe-on-receive only, has been reintroduced as a means of making tracking radars less vulnerable to electronic jamming). The first Tachi-6's were deployed in 1942, and gave ranges up to 185 miles on high flying aircraft.

Following the Tachi-6 came the only slightly less cumbersome (18 ton) but transportable Tachi-7 for the same purpose, operating on frequencies around 100 MHz and with a maximum range similar to that of the earlier set. About 60 Tachi-7's were built and from October 1943 these were deployed throughout the home islands and occupied territories. For service in the combat zone a yet lighter set was needed, and early in 1944 the 4-ton Tachi-18 appeared which also operated on frequencies around 100 MHz.

None of the early warning radars mentioned above could give indications of altitude so the Tachi-20, which operated on frequencies in the same band as the Tachi-6, was developed. This set did not go into service until March 1945 and about a dozen were deployed. The

Tachi-35, operating on 82 MHz, entered service for the same purpose in May and only a few were deployed before the war ended.

Japanese Army work on the development of precision radars for searchlight and AA gunlaying received a considerable boost early in 1942, following the capture the American and British bases at Corregidor and Singapore. At Corregidor the Japanese captured an intact SCR-268 and a badly damaged early warning radar, probably an SCR-270. On Singapore they captured badly damaged examples of an early warning set and a gunlaying radar, and also found some useful technical manuals.

As a result of these finds two Japanese searchlight and fire control radars appeared, the Tachi-1 and the Tachi-2, both operating on frequencies around 200 MHz and employing many techniques copied from the SCR-268. The reason for the two different radars was that two companies, Sumitomo (Tachi-1) and Tokyo Shibaura (Tachi-2) had each received a contract to develop an AA gunlaying radar (a further example of the fragmentation of effort which characterised Japanese radar at this time). Neither radar was not successful, however, and in total only 65 were built. Sumitomo then switched production to the Tachi-3 (72 to 84 MHz) based on the British Gunlaying Mark II radar; about 150 of these were built and it became numerically the most important Japanese set in this category.

The Tachi-4 was a mobile set intended to replace the Tachi-2 and operating on the same frequencies, but it was unsuccessful and saw little use. However a development of the Tachi-4, the Tachi-31, proved much more successful; about 70 had been built by the end of the war it had become the most important precision radar operating in the 200 MHz band.

From the beginning of 1944 the Tama Institute worked to produce a Japanese Army version of the German Wuerzburg radar, one of which had been delivered to Japan by submarine. Before it could go into mass-production, however, it was decided to re-engineer the set to Japanese specifications. As a result of this and the severe disruption in production caused by the B-29 attacks the Tachi-24 , as the set became known, was still in the prototype stage when the war ended.

The only Japanese Army airborne radar to go into mass production was the 150 MHz Taki-1 ship-search equipment, fitted to maritime patrol aircraft and torpedo bombers. This radar first saw operational use in the fall of 1944.

As has been said, the development of radar for the Japanese Navy proceeded entirely separately from that for the Army. There was even a security barrier between the two programs to maintain this separation. Thus the Nihon Musen company, one of the three principal Japanese concerns producing radar during the war, had to divide its main plant at Mataka near Tokyo into two when building equipment for the two services; there was even a ban on company engineers working on the different contracts from exchanging information.

The Japanese Navy system of designating radars was quite different from that used by the Army. Sets were categorized by purpose. Thus the Mark I radars were all ground early warning sets; the Mark II's were ship-borne sets, the Mark IV's were ground precision radars for searchlight and/or AA gunnery control and the Mark VI's were airborne ship-search equipments. A notable departure from this system was the Gyoku-3 designation for the Navy airborne interception radar.

The main research and development agency for Navy radars was the Second Naval Technical Institute near Tokyo. The first Navy set to go into production was the Mark I Model 1 early warning radar which operated on frequencies around 100 MHz. The first of these to become operational was installed at Rabaul in the spring of 1942 and altogether about 80 were delivered. The next set in this category to enter production was the Mark I Model 2, a mobile radar operating on frequencies around 200 MHz; about 300 of these were built. This set in its turn was followed into production in 1943 by the lightweight Mark I Model 3 operating on frequencies in the 147 to 165 MHz band. About 1,500 were built and it saw widespread use. The reader will note the many similarities between this family of early warning radars, and the quite separate family developed for the same purpose by the Army.

The first Japanese Navy shipborne radar, the Mark II Model 1 operating on frequencies around 200 MHz, began sea tests on the battleship Ise in March 1942. A few months later the radically different Mark II

Model 2 appeared, operating on frequencies in the 3,000 MHz band and using a 2 Kw magnetron as power source (it is interesting to note that at the beginning of 1942 Japanese work on microwave radar was only a few months behind that in the USA, though the gap increased rapidly during the course of the war). More than 400 of these microwave radars were built during the conflict, and versions were fitted to ships of all sizes and submarines. The Navy re-engineered its own version of the German Wuerzburg and re-designated it the Mark II Model 3; as in the case of the Army version, however, this radar was only in the prototype stage when the war ended. The Mark II Model 4 was a lightweight set operating on frequencies around 150 MHz and fitted to small ships and submarines. In most cases these ship-borne radars were intended to provide air and surface warning, with anti-aircraft and surface gunnery control as an auxiliary function; this requirement for radars to perform conflicting functions was beyond the capability of Japanese technology at the time, and resulted in sets whose performance was mediocre in most respects.

For the control of the searchlights and anti-aircraft guns defending its shore bases, the Japanese Navy developed its own version of the SCR-268, the Mark IV Model 1, which also operated on frequencies around 200 MHz; the first of these went into operation at Rabaul in November 1943, and in all 80 were built. Following this set in production was the Mark IV Model 2, with several improvements to make it easier to build and maintain. The Mark IV Model 3 was a direct copy of the Army's Tachi-1 (and a rare example of inter-service co-operation); the Navy found it as unsatisfactory for searchlight control as the Army had for gunnery control, however, and few were built.

Towards the end of 1941 the Japanese Navy began work on a lightweight ship-search radar for its patrol aircraft. This resulted in the Mark VI series of equipments operating on frequencies around 150 MHz, which first entered service in 1943. Altogether some 2,000 examples of this radar were built and the set saw wide scale use.

When the war ended the Navy had under development an airborne interception radar for night fighters: the 150 MHz Gyoku-3. Although tests had begun, the radar was too late to see action.

Throughout, the picture of Japanese radar development up to the end of World War II is one of piecemeal developments of sets, which in most cases brought little improvement in capability over their predecessors. The need to run almost completely separate and parallel radar development programs for the Army and the Navy reduced the effectiveness of the nation's limited radar research effort; and individual services even placed contracts with different companies to produce radars to do the same job. The outcome was that the small Japanese electronics industry found itself required to turn out relatively small production runs of many different types of radar. It proved quite impossible to keep pace with the quantity and quality of Allied radar development and production. The large scale use of countermeasures against the Japanese radars did not begin until April 1945, and in the four months between then and the end of the war there was no time to react effectively. The impact of the US jamming on the Japanese air defense system is covered in the next Appendix.

DETAILS OF THE MAIN TYPES OF JAPANESE RADAR

Note: Because most of these radars ran to numerous sub-types, the technical details given below should be regarded as representative for the type only.

ARMY RADARS

Type A Bi-static Doppler Interference Detector.

Quantity built about 100 — 3, 10, 100 and 400 watt versions.

First used 1941

Maximum range up to 440 miles

Frequencies 40 - 80 MHz

Note: although strictly speaking this equipment was not a radar, it has been included in this list for completeness.

Tachi-1 Ground Searchlight and AA Fire Control Radar

Quantity built 30 — Peak power 5 Kw

First used 1943

Maximum range about 12 miles

Frequencies used: around 200 MHz

Tachi-2 Ground Searchlight and AA Fire Control Radar

Quantity built 35 — Peak power 10 Kw

First used 1943 — Pulse length 2 microsecs

Maximum range about 25 miles — PRF 1,000

Frequencies used: around 200 MHz

Tachi-3 Ground Searchlight and AA Fire Control Radar

Quantity built about 150 — Peak power 50 Kw

First used 1944

Maximum range about 25 miles

Frequencies used: 72 to 84 MHz

Tachi-6 Static Early Warning Radar

Employed omni-directional or wide-angle transmitter aerial, and up to four separate directional and movable receiver aerials.

Quantity built 350 — Peak power 10 - 50 Kw

First used 1942 — Pulse length 25 - 35 microsecs

Maximum range 185 miles — PRF 500 or 1,000

Frequencies used: 68 to 80 MHz

Tachi-7 Transportable Early Warning Radar

Quantity built about 60 — Peak power 50 Kw

First used 1943

Maximum range 185 miles

Frequencies used: around 100 MHz

Tachi-18 Mobile Early Warning Radar

Quantity built 400 — Peak power 50 Kw

First used 1944

Maximum range 185 miles

Frequencies used: 94 to 106 MHz

Tachi-31 Ground Searchlight and AA Fire Control Radar

Quantity built 70 — Peak power 50 Kw

First used 1945

Maximum range 25 miles

Frequencies used: 187 to 214 MHz

Taki-1 Airborne Ship-Search Radar

Quantity built about 1,000 — Peak power 10 Kw

First used 1944

Maximum range about 60 miles on a large ship

Frequencies used: around 150 MHz.

NAVY RADARS

Mark I Model 1 Static Ground Early Warning Radar

Quantity built about 80 — Peak power 5 Kw

First used 1942 — Pulse length 10 - 30 microsecs

Maximum range about 90 miles — PRF 530 - 1,250

Frequencies used: 92 to 108 MHz

Mark I Model 2 Transportable Ground Early Warning Radar

Quantity built about 300 — Peak power 5 Kw

First used 1942 — Pulse length 3 - 20 microsecs

Maximum range about 90 miles — PRF 750 - 1,500

Frequencies used: 187 to 214 MHz

Mark I Model 3 Portable Ground Early Warning Radar

Quantity built about 1,500 | Peak power 10 Kw

First used 1943 | Pulse length 3 - 12 microsecs

Maximum range about 90 miles | PRF 400 - 600

Frequencies used: 146 to 165 MHz

Mark II Model 1 Shipborne Air and Surface Search Radar

First used 1942 | Peak power 5 Kw

Maximum range 90 miles on aircraft | Pulse length 3 - 20 microsecs

18 miles on large ship | PRF 500 - 1,100

Frequencies used: 185 to 210 MHz

Mark II Model 2 Shipborne Surface Search and Fire Control Radar

First used 1942 | Peak power 2 Kw

Maximum range 22 miles on large ship | Pulse length 2 - 10 microsecs

Frequencies used: 2,857 to 3,125 MHz

Mark IV Model 1 Ground Searchlight and AA Fire Control Radar

Quantity built 80 | Peak power 30 Kw

First used 1943

Maximum range 30 miles

Frequencies used: around 200 MHz

Mark IV Model 2 Ground Searchlight and AA Fire Control Radar

Improved version of the Mark IV Model 1

First used 1944	Peak power 30 Kw
Maximum range 30 miles	Pulse length 3 microsecs
Frequencies used: around 200 MHz	PRF 1,000

Mark VI Airborne Ship-Search Radar

Quantity built more than 2,000	Peak power 3 - 6 Kw
First used 1943	Pulse length 3 - 10 m'secs
Maximum range 43 miles on a large ship	PRF 700 - 1,200
Frequencies used: 140 to 160 MHz	

APPENDIX H

THE EFFECTIVENESS OF US RADIO COUNTERMEASURES IN THE PACIFIC THEATRE OF OPERATIONS

Note: this Appendix is extracted from the post-war report 'American Radar Countermeasures VS Japanese Flak & EW Radar', prepared by the Air Technical Intelligence Group and dated 10 December 1945.

AA Procedures - Army

Japan was divided into four main Army areas for protection by AA Divisions, the Tokyo area, Nagoya area, Osaka area and the northern part of the island of Kyushu. Each Area Hq seems to have handled all air warning information that affected its own area of control. There was very little liaison between the ground and air forces in such matters as GCI or SLC [ground controlled interception or searchlight control radars]. The only way they could keep track of their own fighters was by constant plane to ground radio chatter, and the various Flak batteries were notified from time to time of the movements of friendly planes by telephone.

The coastal areas around the main cities and military target areas of Japan were protected both by EW stations and by a 'radio fence' using the Doppler system . . . Early warning radars were never used in the actual 'setting on' of Flak radars, but in the last months of the war some thought seems to have been given to this as additional equipment were dreamed up (Tachi-20 and Tachi-35) to measure elevation angle as well as range and azimuth. The only real use they got out of the additional equipment, however, was to use it as an aid to vectoring fighters for intercept purposes.

According to weather conditions, cloud cover, time of day etc, tracking was done by radar or a combination of radar and optical means. When possible, radar was used for obtaining range, and optical means for determining azimuth and elevation (sonic devices seem to have been used in isolated cases, without very much success). Several officers who were interrogated, admitted that on different occasions the operators had difficulty in determining if both the radar and optical devices were tracking the same target.

An effort was made to determine what percentage of the air raids radar and/or optical firing data was used, but no statistics were available - same old story 'all records destroyed', and anyway the Japanese made little effort to keep track of such information. Records of this sort would have been valuable to us in determining the over-all effectiveness of our jamming program.

AA Procedures - Navy

In the early part of the war the Navy was primarily responsible for the defense of all islands in Japan's extensive 'outer circle', but as the war progressed they also took over from the Army part of the responsibility for defending from air raids certain sections in the 'home' islands and a good part of Formosa. These naval Flak positions were mainly around naval bases and the larger seaports of Kyushu, Honshu and Formosa.

When the Flak radars and early warning radars were first set up, little consideration was given to any other problem than convenience of installation. Thus in most cases it happened that the EW sites might be miles from the Flak radars and all data on an approaching raid had to be telephoned to them. This resulted in considerable delay and confusion and so an overall plan was prepared to set up the EW and GL radars side by side. This plan, however, they never got around to carrying out.

To a great extent the Flak radars depended almost entirely on the EW radars for specific data to 'get on' the target. Their range was comparatively short and their searching ability very poor so it was necessary to get warning of an approaching raid as early and as accurately as possible so that the batteries themselves could be prepared . . . Thus when the EW radars were partially jammed on top of this, the meager information obtained had to be telephoned to the Flak radar, it left the whole system in a state of confusion and preparedness. And now add to that the severe jamming of the Flak radars themselves.

Effectiveness of RCM

Japanese AJ Equipments - Army

This subject can be summed up in one word, 'none'.

Japanese AJ Techniques - Army

The Japanese Army had received from Germany the general principals of the 'Wuerzlaus' method and had done considerable work experimenting with it. However the Army operators decided they could read through our 'Rope' well enough and so this method was never used in the field.

Against electronic jamming they had practically no means of counteracting its effect. In some cases azimuth was obtained by a crude sort of D/Fing on the source of the jamming signal by using the point of maximum disturbance on the receiver-indicator, and the range was obtained, if possible, by some radar not too badly jammed. Various Japanese personnel questioned stated that it seemed the 200 Mc frequency was more often jammed in the Tokyo area, while the 78 Mc GL frequency would be jammed west of the Tokyo area. No reason can be found for this opinion. Since they had sets using both frequencies scattered through the various Flak defenses, usually some radar would be partially free of jamming - not that it ever did them much good. (They had no plan or order in the selecting of frequencies for any particular Flak battery. They simply used whatever set was available at the time the battery was placed. Some estimates state that only one out of every eight AA positions was radar controlled.)

When our electronic jamming became serious, they attempted to hasten the research and the solving of production problems they were encountering on the Japanese version of the German Wuerzburg. They felt confident that since its directivity was good, any jamming effectiveness would be greatly minimized except from an aircraft directly within the beam-width of the antenna. The net result was, one Wuerzburg set up for final tests. Also they planned to modify their existing 1.5 meter (200 Mc) equipment so that when jammed they could switch bands either to 1.7 m (176 Mc) or to 1.3 m (230 Mc). This seems to be rather extreme band shifting and no information is available as to how this was to be accomplished. By the end of the war, the Army had only gotten as far with the plan as to send an order through to the labs and manufacturers to start research on the problem. However, very high priority was assigned to the project.

Indications of Effectiveness of Jamming from Japanese Sources

Many Army officers, both technical and operational, were questioned, as well as numerous civilian technicians and radar engineers, concerning the effectiveness of our jamming efforts. In almost every case, the person questioned, in effect, threw up his hands and said 'Our anti-aircraft firing radars were useless under the "wave disturbing" from your aircraft.' They admitted an almost 100% reduction in effectiveness of their Flak radars. And unless means for obtaining optical data were good, the batteries just did not fire when the radars were jammed. As for Rope and/or Window jamming, the story was different. Most personel questioned claimed that experienced operators could track aircraft through the clutter but 'with difficulty'.

The following statements are direct quotes from statements made by several responsible officers connected with technical research and with the tactical use of radar: Col. K. Sataki, Tama Research Institute (radar research and production) 'Highest priority given to anti-jamming studies and to efforts to modify existing radars so that band shifting would be possible.' Lt Gen. Tada, Chief of Tama Institute 'About 10% of the high frequency research effort in all fields, or about 80% of the research effort on radar projects alone, was diverted to the development of anti-jamming equipments.' Lt Col Hiroshi Tominaga, Sig. Sect., Imperial Gen. Staff (was in charge of planning and setting up of radar sites in China and some on Honshu) 'American jamming was so complete that maximum research effort was expended to develop our radar to combat it. Most 'search' experiments [ie with intercept receivers] were dropped' (considerable research had been in progress to develop search receivers by which Allied radars might be Ferreted).

Lt Gen. Tada also expressed an opinion that, through air raids, Japan's capacity for radar production was knocked down to about one third of its former level and its capacity for research to about one half, still he believed that six months would have been sufficient to greatly improve Japanese radar in its ability to combat our jamming. The above statements and opinions can be accepted as the sum and substance of the answers received from almost every person questioned.

There seems to be no available figures on the number of rounds of AA ammunition per aircraft kill, using radar controlled batteries either with or without jamming, but operational officers state that jamming reduced the detection or tracking range of B-29s from approximately 18 to 25 miles down to 1 to 3 miles.

Japanese AJ Equipments - Navy

The Navy, like the Army, had had no time to develop anything to combat our jamming.

Japanese AJ Techniques - Navy

They claim that no foreign information was used in any way in their AJ research. And like the Army, they state that Window and/or Rope jamming caused negligible difficulty. Operators were given 'on the spot' instruction by officers from the naval radar schools, who travelled around to the various sites and conducted tests on Chaff suspended from balloons. Operators were taught to recognize the difference in 'beat' between the Widow return and the target return. Also they attempted to discriminate between the wave shape of a Window return and that of a plane. Window jamming began very early compared with electronic jamming and was first carried out by B-29's [more likely B-24's - author] attacking from China bases. The Japanese claim that this gave them lots of practice tracking through Window echoes, especially in Formosa, and that they had considerable success with their Flak radars there.

But with electronic jamming it was a much different story. Like the Army, the Navy very freely admits that its Flak radars were practically useless at any time electronic jamming was done by American aircraft.

They claim to have first had trouble in the Kyushu district in 'April or May 1945', and later, in 'June 1945', in the Kanto or Tokyo district.

Their plans to minimize the effect of electronic jamming consisted of two parts:

1. Research was started to modify their existing GL radars so that a frequency shift of as much as 10 Mc either side of the original frequency might be attained (this however was never completed 'due to design difficulties', though some experiments were carried out with EW radar so modified and they claimed these were quite successful.)
2. An attempt was made to modify the Mark II Model 2, 10 cm ship-borne to measure elevation angle. Experiments against aircraft indicated a range up to 20 km (12 mi) for this set. However, work on this was not completed either, before the end of the war.

The Mark II Model 2 (10 cm) was also experimented with as an SLC radar and one such set was found at Tsukishima, a branch of the 2nd Naval Tech. Institute in Tokyo.

The S-8A [also known as the Mark II Model 3], a 58 cm Flak radar, was felt to be another answer to the jamming problem, and it was given high priority, but again they failed because of little time and loss of production facilities due to air raid damage.

There was no special training given to radar operators because as in the words of one Japanese officer 'the concrete plan to anti-jamming was not exist'. However, some efforts along that line were made but with doubtful success. Operators were advised to use the 'gain' control in attempting to bring the echo out of the noise, and an attempt was made to do 'lobe comparison by noise amplitude'. What they did was use the receiver indicator as a rough D/Fing unit, using the point of greatest noise amplitude as a means of determining azimuth and elevation; then to get the range they would use the Mark I Model 3 150 Mc EW set. They admitted this method was very inefficient and inaccurate - 'The method to use the enemy's disturbance waves in reverse as our direction finder, afforded us only to discern the approximate direction of the enemy owing to the bad condition for minuteness (they found that pip matching on the maximum strength of our electronic noise was almost impossible due to the wide side-bands of our jamming frequency) and shooting was also difficult.' That classic of understatement just quoted was made by Vice Admiral Nawa, chief of the Megura Park branch of the 2nd Naval Technical Institute.

Many of the individuals questions stated flatly that at night or in bad weather 'When your aircraft "disturbed our locators" we could not and did not shoot.' This seems to have been especially true in Kyushu and the Tokyo areas. Around the Sasebo Naval base in western Kyushu, and in Formosa, they claimed to have had better success - more practice, as they put it.

Very high priority was given to anti-jamming research but nothing was accomplished in the short time they had from April 1945 until the end of the war. Captain Ideura of the Naval Tech Dept., stated that their only hope was the modification of their shipborne 10 cm job, and if this was susceptible to jamming 'then we could not see the way for defense'. And he and other officers and engineers of his department were quite frank in admitting that modification of any radar in the last months of the war was next to impossible. Laboratories and manufacturing plants were being further dispersed; small factories supplying badly needed components were bombed out; and lastly, the airplanes used to conduct tests against their experimental radars 'had to take refuge occasionally' from our planes - and to crown it all, they quite often did not have enough gas to fly the planes to conduct the tests to see whether or not they had a radar that would do the work planned for it.

Vice Admiral Nawa, chief of the Mogura Park branch of the 2nd Naval Technical Institute, complained that 'to do effective research we must get rid of the B-29s, but to get rid of the B-29s we must have radars not susceptible to jamming' - he left off there, unable to come to a definite conclusion. As Lt. Cdr Masaki so ably put it 'In brief, we were troubled by American jamming from beginning to end; our Flak radars did not perfectly get out its faculties.'

After discussing it with numerous officers and engineers of the 2nd Naval Tech Institute, the concensus of opinion was that, by the end of the war, production facilities had been reduced by air raids to about 10%

of normal, and electronic research to about 15 to 20% of normal. Since the Navy was not primarily interested in land-based GL radar, only about 10% of its total electronics research effort was turned to anti-jamming. But this 10% represented practically all the 'brains' involved with the design and production of this type of radar.

They explain this extreme loss of production and research ability not so much by the actual damage from the air raids, but because of:

1. Shortage of parts (mechanical and electrical).
2. Faulty production (experts and technicians drafted, mental distress due to air raids).
3. Shortage of transportation.
4. Loss of production volume by dispersal of factories.
5. Frequent changes of plans.

Of course, 1, 3 and 5 above are plainly due to air raid damage, and behind their inability to maintain any sort of adequate defense against or air blows, was their almost total lack of countermeasures against our radar and our jamming.