ELECTRONICS WARFARE

A REPORT ON RADAR COUNTERMEASURES

Released by the Joint Board on Scientific Information Policy for:

OFFICE OF SCIENTIFIC RESEARCH AND DEVELOPMENT

WAR DEPARTMENT

NAVY DEPARTMENT

Distributed by The Office of The Publication Board

ELECTRONICS WARFARE

A REPORT ON RADAR COUNTERMEASURES

Released by the Joint Board on Scientific Information Policy for:

OFFICE OF SCIENTIFIC RESEARCH AND DEVELOPMENT

WAR DEPARTMENT

NAVY DEPARTMENT

Distributed by The Office of The Publication Board

Revised 10/19/45

ELECTRONIC WARFARE: The Story of Radar Countermeasures

CONTENTS: Page

A Note to Editors and Readers:

The development of radar countermeasures was a cooperative enterprise. Within the Federal Government this cooperation was among the civilian and military staffs of Army Air Forces, Army Signal Corps, and other War Department contributors, the Naval Research Laboratory and Bureau of Aeronautics of Navy Department, and through the work of Division 15 of the National Defense Research Committee of the Office of Scientific Research and Development.

The principal research establishment of the OSRD activity was the Radio Research Laboratory at Harvard University.

In addition there were numerous essential contributions made by the industrial laboratories and contractors; and the producers of equipment in the electronics industry of the country have a unique story of their own to tell of the problem and accomplishments of manufacture.

This release is meant to be a basic report on electronics warfare from which writers and editors may derive a variety of individual stories.

THE JOINT BOARD ON SCIENTIFIC INFORMATION POLICY.

WASHINGTON, D. C., *29 November 1945.*

1. Introduction

THE PERFECTION of new weapons is one of the most important—and spectacular—of wartime tasks. We have seen in this war how greatly new scientific developments have increased the effectiveness of the fighting forces; in some cases new devices may be said to have decided the outcome of an entire campaign. Moreover, we are aware of the enormous scientific effort which must be expended in the perfection of these new devices.

A task of equal importance is the preparation of counter measures to new methods of warfare introduced by the enemy. For every weapon there is a counterweapon. Thus, the chemical mask is perfected as an answer to poison gas, and the antiaircraft gun is arrayed against the buzz-bomb. It can be truly said, that whatever scientists devise, other scientists can to some extent undo.

For this reason, it has been found necessary in World War II not only to assemble large groups of scientists whose sole task is the development of new weapons, but also to assemble similar groups whose assignment is to devise means of preventing the enemy from making full use of new weapons he may bring into action.

Here is a further refinement of the scientific war. On the one hand we have scientists racing to perfect new weapons. On the other, scientists racing to destroy the effectiveness of these devices.

This is the story of one phase of that second race—a story of our successful campaign against the German and Japanese radars. It is a story that is unique in many respects. Of all the many wartime scientific developments, radar countermeasures were perhaps the most closely tied in with actual military operations. Their successful application depended not only on the enemy's tactics, but also on our own. Because of the close connection with both operations and intelligence, radar countermeasures have been shrouded in the utmost secrecy from the very start. Now, for the first time much of the story can be told.

2. The Nature of the Problem

RADAR and related electronic devices have completely changed the tactics of modern warfare by making it possible to "see" and attack an enemy hidden by smoke, fog or night.

When the United States entered the war, thousands of German radar sites defended the continental empire of the Third Reich—sites armed with radars developed before the invasion of Poland. There were chains of long-range stations to give the enemy early warning of the approach of Allied bombers and to enable him to plot the position of our formations en route to their target. There were air-borne radars which enabled the German fighters to find our aircraft at night. Still other kinds of radar were used to direct searchlights and antiaircraft fire, all as part of a plan to make the war in the air prohibitively expensive to the Allies. The German Navy was similarly equipped. As time went on, chains of sea-watching radars covering the entire Atlantic and Mediterranean coasts of the Continent were erected to discover our shipping or signs of invasion.

German radar research had an early start, and the results presented a serious threat to the Allies. Fortunately, because the Germans were confident of a short war, they standardized early on a few types, virtually ending all development and research for an all-important 2-year period after the fall of France. This fatal error in strategy gave the Allies time to develop and apply effective countermeasures against a relatively static system of radar defense.

The Italians never got very far with radar. The best sets in their possessions were some rejected models sold them by the Germans. Upon Germany fell the burden of the radar defense of Italy.

Japanese radar at the start of the war was far behind that of the Allies or of Japan's Axis partner, Germany. Nippon had sets for early warning, searchlight control, antiaircraft direction, and some for surface watching, but the majority were poor copies of early Allied equipments, and most of these were in short supply. Later the Japanese developed more modern equipment, but little of it was produced in time for use in combat.

Both the Japs and Germans, suffering under the impact of our countermeasures, belatedly tried the same thing against us. They were too late. It can be said that we had radar, and got the most out of it; the Axis also had radar, but because of our countermeasures got very little out of it.

The entire countermeasures program has been a race against time, its success has been dependent upon the closest liaison between the laboratories, the Services, the manufacturers, and the fighting fronts, for only in this way could early intelligence of enemy plans result in the production of equipment with the speed necessary to get it into operational use in time.

To insure a maximum of speed in dealing with problems whose details changed from day to day, secret missions were sent to the major fighting fronts; transoceanic teletypewriter conferences were held, and equipments designed to do special jobs were "crash-produced" in model shops and flown directly to the scene of operations, often accompanied by the inventor to insure their effective use. Then there was the all-important planning of the method of use of the new devices; military personnel and civilians, working shoulder-to-shoulder, cooperated more closely than ever before in solving the operational problems as they arose.

3. The Achilles' Heel of Radar

Dr. Vannevar Bush has said that "the new eyes which radar has supplied can sometimes be blinded by new scientific developments." Let us examine some of the weaknesses of radar which lend themselves to exploitation.

It will be remembered that radar works on the principle of echoes. Just as a man, by shouting loudly, can hear the echo of his voice returning from a cliff, so a radar, figuratively speaking, first sends out a loud electrical "sound" and then listens for the faint echo to return. Instead of a sound, of course, a radar transmits a radio signal. In both cases, the original disturbance must be loud if the weak returning echo is to be heard at all. Radar stations therefore send out radio impulses of tremendous strength; all that is needed to detect or hear these signals is a special radio receiver which will tune to the extremely short wavelengths used by the radar.

This represents the first weakness of radio location; because it is constantly sending out strong radio signals, a radar set can be heard at a great distance—in fact, at a much greater distance than the furthest range at which it can detect an object. Thus the radar itself can be easily detected. A radar with a 70-mile range could easily be "heard" well over 100 miles away. An operating radar, in effect, continuously advertises its presence. It is about as quiet, electrically speaking, as an artillery barrage is acoustically.

Second, a radar set betrays not only its existence, but also its exact location by the signal it sends out. It is always possible, by means of a radio direction finder, to determine the direction from which radio signals are coming, just as it is possible to tell the direction from which sound waves are coming by pointing an ear trumpet in different directions until the received sound is loudest. If the direction to a radio station can be measured at widely separated points, and the lines of bearing drawn in on a map, the position of the radio station will be at the intersection of these lines. Once a radar signal has been tuned in on a radio receiver, it is possible by means of an attachment to the receiver to measure the bearing of the radar and thus to determine its location.

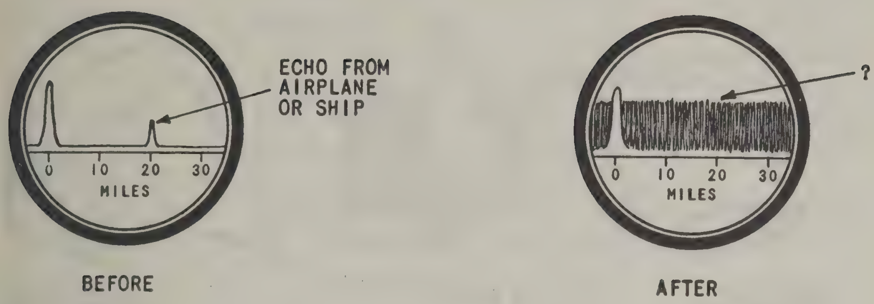
A third weakness of radar sets is the fact that the echo returned from most targets is so weak in strength. The sound returned from the cliff is many times weaker than the man's original shout. A fairly weak noise, therefore, would suffice to cover up the echo. A second man, standing on the cliff and shouting continuously, would prevent the first man from hearing the echo of his own voice.

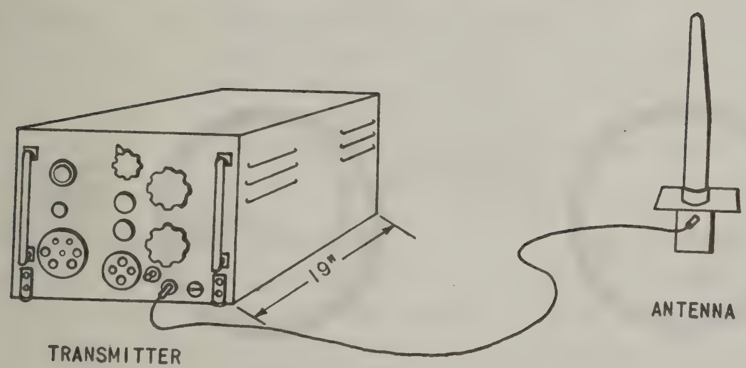
Radars can be blinded in the same way. It is only necessary to provide the target with a device which sends out a radio signal capable of covering up the signals reflected back to the radar by the target. This process is known as electronic jamming. Because each radar set operates on a particular frequency channel, it is necessary that the jammer—which is fundamentally a small radio transmitter—be tuned to that same channel.

A practical radar jammer consists of a tunable radio transmitter provided with a type of modulation which is especially suited to drowning out radar echoes. Any home radio owner who uses an electric razor has a good idea of what such interference means. It has been found that the most effective radar jamming signal is simply a hissing noise similar to the background noise heard in sensitive radio receivers when no program is being received. Such a signal is said to have a "random noise modulation."

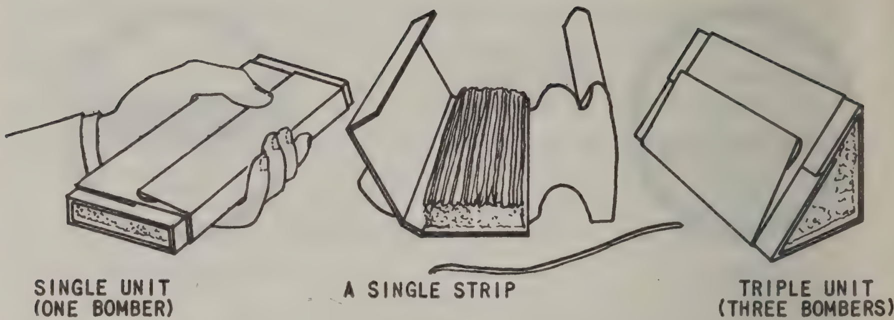
When picked up on a radio receiver equipped with a loudspeaker, a noise jamming signal sounds like a hiss. A radar, however, presents the information it received not aurally but visually. Signals appear as patterns on the face of a cathode-ray tube called a "scope." As seen on this tube the "noise" looks like many fine blades of grass moving about in a random fashion. Echoes from airplanes, which are usually displayed as vertical spikes on the radar scope, simply disappear and become lost in the "grass."

A further weakness of radar sets is the circumstance that they cannot distinguish the nature of small targets. One small object, capable of returning an echo, looks to a radar just about the same as another. To a radar, an airplane or a ship is a small object. It has been found that a number of thin metallic strips, cut to a length proportional to the wave length used by a radar, can return a remarkably strong echo to that equipment. In fact, several thousands of these thin metallic strips, packaged in a small bundle weighing less than 2 ounces, will give a radar echo signal equivalent to one bomber, when the strips are ejected from a plane and allowed to fall freely through the air.

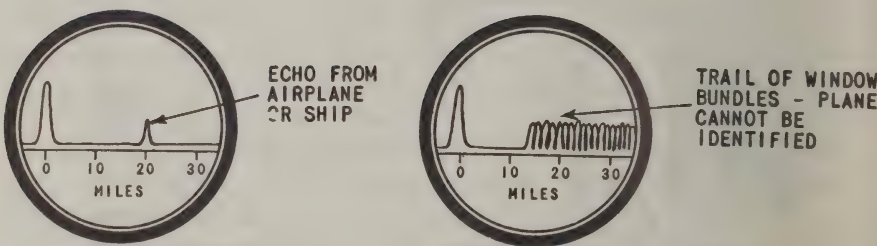




The sketch shows the pattern which might be seen on the face of the radar scope before and after jamming by means of random noises. Below it is a line drawing of a typical radar jamming transmitter widely used both aboard ships and in aircraft.



WINDOW
(DEHYDRATED BOMBERS)



BEFORE

AFTER

The drawings at the top of this page show typical bundles of "Window" while the "before and after" illustrations below indicate the way that the image on the enemy radar scope is confused by the strips of "Window" as they drop freely through the air.

The phenomena is one of resonance. The metallic strips, designated by the code name "Window," are resonant at the frequency of the radio waves sent out by the radar; in this way a relatively small number of strips can return an echo equal to that from a large metal object such as an airplane.

If a number of Window packets are dropped out of a plane in succession, a trail is produced in which a radar can no longer distinguish a real target. The echo from an aircraft is simply lost among the echoes from the Window. It is much as if the planes were being concealed by a smoke screen of metallic foil.

In brief review, the weaknesses of radar which can be exploited are these: First, a radar is really a powerful radio transmitting station which can be heard at a considerable distance. Second, like any radio station, its direction and location in relation to the listener can be determined by means of radio receivers equipped with direction finders. Third, since the radio echo that they receive from most targets is very weak, relatively little power is required to cover up that echo by sending out a jamming signal from the target. Fourth, radars have difficulty in distinguishing between actual targets and free falling strips of foil cut to the proper length.

To knock out the enemy's radar, all four of these weaknesses can be exploited. It is also necessary, insofar as is possible, to prevent him from doing the same to you. One reason the Allies achieved their victory as quickly as they did was that they were always one step ahead of the enemy in the jamming war.

4. December 1941

America's entry into World War II brought about immediate changes in our military policy in relation to radar. Prior to Pearl Harbor, our task had been to develop radar, and to evaluate its possibilities. After Pearl Harbor, with definite enemies and a definite order of battle in mind, the emphasis shifted to the quantity production of our radar developments as required.

Radar countermeasures followed much the same course. Prior to the war, research work of a long-range character had been carried on in our Service laboratories. After Pearl Harbor, it became clear that if the enemy's radar was as useful to him as we expected our own would be useful to us, it would be necessary to put a major effort into the developing of countermeasures against specific German and Jap equipments. This feeling was reinforced by the experience of the British, who had already used countermeasures successfully in the defense of their homeland, and attached a high and increasing importance to this activity.

In the realization that an expanded research and development program would be required, the Services formally requested, late in December 1941, that the National Defense Research Committee undertake a project in the field of radar countermeasures.

The research and development work carried out represent a very considerable contribution to the radio art. Tunable receivers were designed, capable of continuous coverage up to frequencies 100 times as high as those attained by any prewar commercial equipment. Transmitters operable over unprecedently wide frequency ranges had to be developed, and made to give power outputs far larger than those previously deemed feasible at frequencies higher than ever before reached by such equipment. Tubes of special characteristics, embodying entirely new principles, had to be designed and produced in order to make many of these transmitters possible.

Unusual antennas, capable of operating over wide frequency ranges without any adjustment, presented another difficult problem which was successfully overcome.

In addition to this strictly radio development work, new fields had to be explored in connection with the metal foil radar reflectors; not only was it necessary to carry out research on the principle of operation of these devices; it was also necessary to create the new machines and new manufacturing processes needed to produce and to dispense from airplanes the many billions of foil strips required by our forces in their successful prosecution of the war.

In all, Service orders for countermeasures equipment totalled upwards of $300,000,000, representing more than 500,000 individual items exclusive of "Window," of which some 20,000 tons were produced. Approximately two-thirds of the dollar value of the Service orders represented equipment developed with the help of the NDRC.

The Service and NDRC research and development program in the field of radar countermeasures cost roughly $35,000,000. Of this total, the NDRC spent approximately two-thirds, or $23,000,000. The NDRC funds were allocated as follows: $15,000,000 to a central University-sponsored laboratory; $7,500,000 to industrial laboratories, and $1,000,000 to a field laboratory located in England.

The various organizations engaged in this program under Service and NDRC sponsorship worked in the closest collaboration. Certain groups specialized in the development of new sources of jamming energy—others specialized in the development of equipments and techniques utilizing these sources of power for countering radar or other electronic weapons devised by the enemy.

5 (a). *Alaska and the Jap Radar That Wasn't There*

In June of 1942 the Japanese made their first and only landings on North American soil, on the islands of Kiska and Attu in the Aleutians.

From the standpoint of the Japanese defenders, these Aleutian islands were provided with excellent natural fortifications; from the standpoint of the United States invaders they presented an imposing military problem. The steep shores of islands such as Kiska meant that landings could only take place at a few beaches where attackers would be exposed to direct fire from the hills above. It was realized from the start that special efforts would have to be made to neutralize the enemy's defensive power and to increase the element of surprise with which our attack would be carried out.

In view of its isolated location and high terrain, Kiska represented an almost ideal location for a radar station. This meant that the Japs, by using radar, could be forewarned of the approach of an invasion force when such a force was still many miles out at sea.

During the invasion of Guadalcanal in August 1942, United States Marines had captured some Jap radar equipment. One of the features of this gear was a billboard-sized antenna whose construction resembled that of a bedspring. Later on in 1942, service intelligence officers were puzzled by two suspicious looking structures which showed up in photographs of Kiska taken by photo-reconnaissance planes. An alert countermeasures officer remembered the Guadalcanal radar—the hunt was on.

It is very desirable to confirm the suspected nature of these installations, and it was particularly desirable, from the standpoint of future countermeasures, to determine the operating frequency if they were radars. The quickest way to get this information would be to equip an airplane with the necessary radar intercept equipment and speed it to the theater.

In December 1942 the Army Air Forces ordered a B–24 fitted out with the latest equipment available for this purpose.

In February 1943 this plane was already based at Adak in the Aleutian Islands and was ready to fly radar investigation missions westward over Jap-held territory. Operated by two AAF countermeasures operators, the receiving equipment did its job: two unfamiliar radar signals were heard, and their origin traced to a point which coincided with the suspected site. It was the first time, in fact, that enemy radar signals had been heard on American-built countermeasures equipment. A new method of securing military intelligence had been born: radar reconnaissance had taken its place beside photo-reconnaissance.

From that time on, the Kiska radars were kept under constant observation. One quadrant of their beam was found to be shadowed by the island's volcano: knowing this blind direction, our bombers were able to fly an approach course which brought them in undetected.

5 (b). We Prepare to Invade Sicily

In the Mediterranean theater, the business of systematically spotting enemy radars by listening for their electronic "shouts" really began shortly after the North African landings. Reports of highly accurate gunfire from German coastal batteries became a matter of concern not only to the Theater Commander, but also to Headquarters, Army Air Forces, at Washington. It also became apparent that enemy early warning radars and radar-controlled gun batteries, particularly those along the coast of Sicily and Sardinia, could be instrumental in removing the element of surprise from the contemplated Sicilian invasion, and could greatly increase our ship and landing craft losses during the actual landing operations.

Cables were exchanged on this subject in late 1942 and early 1943. By March 1943, the need for a United States program to investigate enemy radar defenses in the North African Theater became urgent, and high priority was placed on the equipping of a second search plane, which by this time could be equipped with improved gear easily capable of spotting the German radars. This plane, known popularly as a "Ferret," was fitted out in slightly over a month's time.

In addition to prototype radar intercept equipment built by the NDRC, this plane carried with it to the theater a civilian engineer of high professional standing who had been requested by the Army Air Forces to accompany the expedition as its technical advisor. Within a month after the North African Theater's request, the Ferret was flying on regular operations off Sicily.

These radar investigational flights, carried out at night in blacked-out, black-painted planes, had a considerable air of mystery about them. Flames from exhaust pipes were carefully shielded to prevent visual observation by enemy night fighters, which constituted the chief danger, since the Ferrets tried to avoid enemy flak as much as possible. An added precaution against enemy interception was a specially installed radio device which would cause warning lights to flash in the pilot's compartment when the Ferret plane was being tracked by German night-fighter's radar.

The night investigational flights usually followed a course along a line generally parallel to that section of the enemy coastline under observation. Then, if a German radar signal was heard, its general direction was determined by means of the radar direction finding equipment aboard the plane. Several such readings, or "fixes," on the same radar station usually provided data of sufficient accuracy so that photo-reconnaissance planes could later be directed to the area to take pictures of the actual radar site.

Before the arrival of the Ferret mission in North Africa, observations of German radar signals were being carried out in the Mediterranean area by an RAF squadron of Wellington bombers which had been fitted out with British intercept equipment. This equipment was not designed to determine the direction from which intercepted enemy radar signals were coming; the fact that the RAF planes nevertheless did locate a number of radar stations represented a real tribute to the gallantry of their crews. British "Wimpeys" were accustomed to cruising around at low altitude in the vicinity of a suspected radar site and locating the radar by ascertaining the area in which the signals were loudest. In order to locate the enemy sets with any sort of accuracy, it was necessary to fly entirely too close to the well-defended radar sites for comfort. Needless to say, the experience of the British investigational operators proved a great help to the newly arrived American group.

Since the wave lengths on which most radars operated were far shorter than those for which commercial radio direction finders had been designed before the war, entirely new equipment was developed for the job. The first American attempts to locate the source of intercepted radar signals were crude enough; they took the form of a system of homing. Fixed receiving antennas were used, and the direction to the unknown transmitter was determined by altering the airplane's course until two audible tones were equal in strength. However, when this occurred the plane was headed directly toward the radar under observation, and unless the procedure was carried out at some distance from the site, it was likely to become dangerous since flying too close to an enemy radar is not exactly healthy.

There was another serious disadvantage to the homing method. Since more than one bearing had to be taken in order to establish the location of a given radar station, the search planes had to zigzag a good deal, which made navigation on their night flights extremely difficult.

Besides locating the German radars, the original Ferret and its many successors unearthed a good deal of information about German radar strategy in the Mediterranean. The following is a good example. At one point in planning the invasion of Sicily, it became necessary to know whether the German coast-watching radars, which were primarily used to plot Allied shipping, could also be used to plot aircraft. One evening, the Ferret airplane, equipped this time with jammers in addition to receivers, flew out across the Mediterranean to a point near the coast of Italy, where it was brought under observation by several German radars. By tuning in the different signals in his receiver, the countermeasures officer on the plane knew that his plane was being looked at by at least three early warning radars. He also heard one or two coast-watching radars about their usual business of sweeping back and forth on the lookout for ships. The latter sets had up until that time displayed no particular interest in passing aircraft, which were investigated exclusively by the sets used for aircraft observation.

On this occasion, the countermeasures officer turned on his jamming transmitters and put the three early warning radars out of action one by one until the German "eyes" were thoroughly blinded. Then, after a slight delay, the expected happened. The German ship-watching sets ceased their normal business of scanning the surface of the Mediterranean; they eagerly pointed in the direction from which the jamming came in order to see what was going on. Wherever the Ferret flew, the coast-watchers followed it. The evidence was conclusive that both early warning and coast-watching radars would have to be jammed in order to prevent the Germans from getting an idea of the extent of our aerial attack during an invasion. The officer had matched wits with the German radar operators on the ground many miles away, and had won.

The enemy radars thus located by the well-equipped Mediterranean Ferrets were marked for destruction before the landings in Sicily and Italy itself. Some were destroyed by bombing; others were pounded with Naval gunfire. The enemy had to be denied advance notice of the strength and disposition of our forces.

For the landings at Salerno, 50 newly developed radar jammers were flown direct from the factory to the Mediterranean theater, there to be installed on landing craft by a United States Navy countermeasures team. These jammers made it doubly sure that the Germans got no help from their electronic "eyes."

5 (c). Flak Evasion—How To Ruin a Billion-Dollar Investment

THE OVER-ALL Allied plan for the air phase of the European war had two basic parts: the British would area-bomb Germany by night, while the Eighth Air Force in England, and the Fifteenth Air Force in Italy, would pinpoint-bomb by day. This plan, it is now clear, was soundly conceived. But it is easy to forget that the success of the American attack once hung in the balance.

Committed to daylight operations, the U. S. B–17's and B–24's went into battle in tight defensive formations which allowed their heavy armament to provide mutual protection against fighter attacks. Moreover, with large, tight formations a very desirable concentration of bombing could be achieved. These advantages, however, were not obtained without cost, for our compact air squadrons provided the German antiaircraft guns with especially juicy targets.

From early in the war on, the Germans had been preparing to meet the Allied air attack, and their antiaircraft defenses enjoyed the very highest priority. Starting in 1940 with 88-mm. antiaircraft guns, their artillery was soon improved by the addition of an improved 88; later on, 105- and even 128-mm. cannon appeared. By the end of the war, it was estimated that the Germans had 16,000 heavy guns in action, and their important targets were defended by the largest concentrations of antiaircraft weapons in the history of warfare.

As important as the guns was the equipment for fire-control. The Germans had standardized early in the game on a satisfactory predictor and optical fire controller; by April 1940, the first of what was to become a standard line of fire-control radars appeared. Radar, optical controller, and predictor were used as integrated units. At first four guns were assigned to each of these units; later, as gun production began to outstrip radar production, this number rose in some cases to 8 and even to 16.

The radars, known by the code name "Wurzburg" were used not only at night, but also in the daytime when visibility was poor. They were capable of tracking aircraft with a precision equal to that obtainable with optical control. In 1945, the Germans had about 4,000 Wurzburgs or Wurzburg-type radars in service. Taking into account the 10 trained operators required to run each set, the Wurzburgs represented an investment of roughly one billion dollars.

All in all, the flak defenses of the greater Reich were extremely formidable. They were particularly menacing to the special type of bombing formation used by the USAAF. Any antiaircraft gun, when steadily aimed and fired at a fixed point in space, will land the majority of its shells within a certain space enclosing the point of aim. (Inherent inaccuracies in fuse setting, etc., cause a certain proportion of the shots to miss.) Now it happens that the German antiaircraft guns, in firing at a fixed point at the same altitude as our bombers, could land over 80 percent of their shells inside a space which just enclosed the standard United States bombing formation. The German fire-controller had only to aim at the center of our formations in order to assure 80 percent of his shells an excellent chance of hitting one of our planes. As a result of these and other characteristics of the German guns, an individual United States plane in a tight formation ran a several times greater risk of being hit by flak than did a single plane in one of the RAF's loosely knit "bomber streams."

Although radar control of antiaircraft was used by the Germans during many daylight engagements (in view of haze, local smoke screens, etc.), the United States Air Forces' need for radar countermeasures became really acute when bombing with the aid of radar was begun. As soon as our heavies received fighter protection, the Germans' only defense against bombs through the overcast was radar controlled AA fire—and radar is susceptible to jamming.

The British had been faced with the same problem in the course of their night attacks, and their planes had first begun to drop the metallic foil strips, known as Window, during the saturation raids on Hamburg in July 1943. Results were spectacular; the RAF's losses were cut to a small fraction of those sustained in previous attacks. German radar operators were heard to exclaim: "The planes are doubling themselves!"

By May 1943, it had been demonstrated by United States engineers working with the United States Air Force that in England the German gun-laying radar was indeed used against daylight raids, and by October of that year the AAF was ready for an operational test of an electronic jammer known as "Carpet."

This equipment has been designed by an NDRC laboratory early in 1942, with the support of the Signal Corps well before the Army Air Forces had even begun their operations in Europe. Based on intelligence received from the British and originally thought of as a solution to the British countermeasures problem, the Carpets turned out to be a "natural" for the United States heavy bombers. Theoretical considerations showed that when carried one-to-a-plane—at least in the early days—the Carpets ought to be able to send out an "electronic raspberry" quite capable of knocking out the Jerry radar fire control.

On the basis of these calculations only, and in advance of an actual Theater requirement, Headquarters Army Air Forces had authorized the procurement of a number of prototype Carpets.

Procured in record time by the Signal Corps, these sets were flown to England in the summer of 1943 and were installed in planes of two United States heavy bombardment groups, with the aid of United States civilian scientists who were at that time attached to a British countermeasures laboratory.

In October 1943, the Germans got their first taste of United States jamming. During the first raid to Bremen, Germany, the Carpet-equipped planes suffered losses less than one-half those of the non-equipped planes. The Carpets had clearly done their job well. Radar countermeasures in the Strategic Air Forces had come to stay.

Meanwhile, the Mediterranean theater had not been idle. Air Forces countermeasures officers, who had come over with the first Ferret planes, had been spark-plugging requests to Washington for the new jamming equipment. The Germans were to find their southern antiaircraft radar defenses also jammed.

The American Air Forces, who has been the first to exploit electronic jamming of these radars, added the second countermeasure Window to their bag of tricks in December 1943. Since the growing size of our forces required the combat formations, or "boxes" to fly in line, Window tossed out by the first box laid down a trail in the sky in which the German radars were powerless to track the following planes. Carpets were eventually in every plane, and the combination of Carpet and Window jamming proved to be far more effective than either type alone.

The need for flak radar countermeasures grew steadily after their introduction. The average number of operational days per month increased, with the advent of radar bombing, from roughly 9 in 1943 to around 22 in 1944. During the winter months of November and December of 1944, and January 1945, the percentage of missions carried out from England with the aid of radar bombing ran 94, 67, and 73 percent, respectively.

Blind bombing greatly increased the weight of the air attack on Germany, not only because of the increased number of days on which operations were possible, but also because the flak losses sustained on blind missions were lower. This fact permitted more attacks to be made; for example, on D-day, the strategic air forces in England (which was usually able to put up about 1,500 planes on maximum effort missions) flew 2,490 sorties.

It will be seen that radar countermeasures played a major role in keeping these losses down. The decline of the German fighters left radar-controlled antiaircraft fire virtually the sole air defense of Germany on overcast days. Although the losses to fighters had far exceeded the losses to flak in the first part of the air war, by the late summer of 1944 this situation had reversed itself; in August and September 1944, 445 planes were lost to flak, whereas only 198 fell victim to fighters.

Although the effectiveness of our countermeasures was clearly demonstrated by the reduction in losses during the first raids, it became harder and harder to draw valid conclusions from loss data, since no two attacks are run off exactly alike under exactly the same conditions of weather over the target, etc. The first real evidence of the success our Carpets and Window "Flak Pills" were having, came after the fall of Rumania, when Italy-based AAF countermeasures officers seized the opportunity to interrogate German gun crews captured near the heavily defended Ploesti oil fields. Later, when it became possible after VE-day for Army officers and civilian scientists to cross-question members of the Luftwaffe, from the generals right on down to the Wurzburg operators, the answer became abundantly clear: the advent of countermeasures on a large scale reduced the effectiveness of Wurzburg-controlled antiaircraft fire to 25 percent of normal.

How much grief this caused the enemy can now be pictured. Committed as they were to an enormous investment in their Wurzburg radars, the Germans had tried feverishly to keep their sets in operation.

Antijamming attachments were hastily devised and rushed out into the field in the hope that they would cut down the effectiveness of our jamming. In all, some 13 of these devices saw service; 19 additional schemes were under development at the end of the war.

There were two basic ideas behind these attachments: to avoid our electronic jamming, the Germans tried to shift the operating frequency of their Wurzburgs. To avoid Window, they built gadgets which would enable the radars to distinguish between moving and stationary targets.

However, the anti-Carpet devices made their radars vulnerable to Window and the anti-Window devices made them vulnerable to Carpet, because of difficulties in using both devices at once. For this reason, our decision to combine the two countermeasures was a particularly happy one. The answer to all the German attachments was simply more jamming. As it turned out, the constantly growing scale of the Allied countermeasures made the German antijamming devices more or less obsolete before they could be placed in service.

More and more of the German scientists with radar and electronics experience were pressed into the search for workable antidotes to our jamming. At one time, toward the end of 1944, the frantic search had reached a peak. According to a reliable German estimate, 90 percent of their ultra-high frequency engineers were working on antijamming attachments. An average figure was certainly 50 percent, or roughly 4,000 people, whereas only about one-tenth that many trained United States engineers were employed in devising radar countermeasures. The Luftwaffe, in desperation, even announced a public competition, with prizes totalling 700,000 Reichsmarks (free of all taxes) for the best solution to the problem of Window.

In their rush to save the Wurzburgs, the Germans were distracted from the development of microwave radar, which had so brilliantly been exploited by the Allies. Although a working sample of this Allied equipment had been recovered from a crashed bomber as early as January 1943, the Germans were unable to take advantage of a golden opportunity to copy the equipment which had fallen into their hands and modify it for antiaircraft use. Although this possibility was understood, the urgent need to save some small part of the Wurzburg investment diverted too many men. To this extent it may be said that Allied countermeasures not only jammed the Wurzburg radars, but also the German scientists.

Since at least 10 men are required to keep each Wurzburg in operation, our countermeasures tied up roughly 40,000 trained enemy troops who could have been better employed elsewhere. What had been a billion-dollar antiaircraft defense, turned out to be a liability.

By VE-day, at least two radar jamming transmitters were carried in every heavy bomber of the Strategic Air Forces. The scope of this undertaking becomes clear, when it is remembered that these equipments were invented, fabricated, and shipped to an operating theater, where they were installed, and the air crews trained in their operation—all in the period after America's entry into the world conflict.

In all, some 10,000,000 pounds of aluminum foil in the form of Window strips were dropped over Europe by our British-based bombers alone. As a result of this demand, United States aluminum foil production was tripled during the war. Seventy-five percent of this total capacity was devoted to the manufacture of Window. The aluminum foil, which our cigarette packages and candy bars did without, now lies cluttering up the fields of Germany.

During the period from September 1944, until May 7, 1945, heavy bombers based in England flew 30,000 sorties against heavily defended strategic targets under blind conditions. According to official figures, the average flak loss rate for this type of mission was one-half of 1 percent, thus accounting for a total of 150 planes in the period under consideration.

Since all evidence has shown that the effectiveness of German radar-controlled antiaircraft fire against blind strategic missions during those months was approximately 25 percent of normal, it can be said that radar countermeasures undoubtedly saved the United States forces in England roughly 450 planes and 4,500 casualties. The cash value of 450 four-engined aircraft alone is approximately $150,000,000, or about twice the cost of the entire flak countermeasures program. Roughly, the same considerations apply to our strategic Air Force in Italy whose size was fully half that of its British-based counterpart.

5 (*d*). *Breaching the Radar Ramparts of Fortress Europe*

The invasion of Normandy has taken its place as one of the greatest military operations in the history of the world. The success of this frontal assault on the best defenses which could be erected by an ingenious and resourceful enemy can largely be credited to superb military planning.

It was impossible to conceal the intentions of an invasion from the Germans. However, the exact time and place could pe concealed, and it was of paramount importance to the success of the operation that this information be withheld from the enemy until the last possible moment.

As an integral part of their Northern France defense system, the Germans had erected hundreds of radar stations, which, if unmolested, would not only have given warning of the approach of Allied planes and ships, but would also have made possible the direction of gunfire against the attacking force under "blind" conditions.

To give some idea of the density of these radar installations, along the 200 miles of coast line between Dieppe and the tip of the Cherbourg peninsula, no less than 50 air-warning and coast-watching sites were found, each with an average of 2 radars per site. In one section, there was an average of 1 radar every 1½ miles.

Moreover, the Germans took unusual pains to diversify their electronic defenses: no fewer than 12 separate and distinct types of radars were to be found along the so-called invasion belt! Often these sets would be arranged for double duty: early warning and antiaircraft fire control sets were adapted for the control of coastal defense guns.

It is no wonder that the impressive German radar defense was one of the major topics for discussion at the invasion planning conferences. It was given added importance by the fact that operation was sheduled to begin under cover of darkness. By jamming the radar, or otherwise putting them off the air, it would be possible to prevent the enemy from finding out where our forces were concentrated. There were two main countermeasure problems: diversions, and the jamming of coastal gun-laying radar.

In the discussions on how best to put the enemy radar out of action, two possibilities were considered: bombing or strafing plus jamming. It was agreed that both of these propositions would be exploited: as many radars as possible would be shot up, and the rest would be jammed. Complete reliance on bombing would be unwise, since it was perfectly possible for the Germans to hold carefully camouflaged radars in reserve—radars that would not be turned on until the need arose. And even a few radars, left unjammed, could be dangerous. Accordingly, the Air Forces were assigned the task of attacking the radars which had so carefully been spotted by low-flying British and American photo-reconnaissance planes and by radar search receivers. In addition, both Navies undertook the tremendous task of fitting their many hundreds of ships with jamming equipment.

Diversions require careful planning. If all the radars in one particular area are completely jammed, the enemy will suspect that something is happening in that vicinity, and will usually send forces out to investigate. However, in order to be successful, the jamming must be 100 percent complete—something hard to achieve in practice. Each jammer can take care of one radar channel. If many radars are present, each on a different channel, a proportionate number of jammers is required. One or two radars, not jammed, can give the show away. The problem presented by the many types of German radar was not easy.

A more successful sleight-of-hand is one in which small targets are made to look like large ones. In this way a few planes will resemble a formation, or a few ships a fleet. We have seen how 2 ounces of aluminum strips can give a radar echo similar to that from a plane; 10 Window bundles thrown out all at once will give a fair imitation of 10 planes. Moreover 10 bundles released close to the water cannot be distinguished from a ship. However, once the strips are falling freely, their forward velocity stops, and an alert operator notes that his "targets" are standing still. If, however, a complicated situation is developing rapidly and the radar screen is partially cluttered with jamming, even the best operators will be hard put to it to say exactly what is happening. If an enemy operator reports large forces approaching when only small ones are actually there, our purpose has been accomplished. Most diversions are planned on such a basis.

In the case of ships, confusion and screening can be produced by firing "Window" rockets or shells from the guns of the vessels themselves. "Window" can also be dropped from airplanes overhead. Still another possibility is the use of large metallic screens so arranged that a flat surface is always presented to the enemy radar; devices such as this are known as corner reflectors and under some conditions can make a small ship look like a large one.

Once the over-all plan has been adopted, preparations for the actual event were pushed full speed. The Air Forces and the two Navies had an installation problem of the first magnitude.

In order to determine the requirements for ship protection, a section of coast along the Firth of the Forth in Scotland was picked out for its resemblance to the Normandy littoral. Captured German radars of the three main types were set up on this practice shore. At sea, countermeasures-equipped Navy ships, landing craft and aircraft played a game of hide-and-seek with the radar operators on land while British and American civilian engineers stood by as umpires.

The United States Navy's own installation program was well handled by teams of officers and enlisted men specially trained for the job and operating as independent units for reasons of secrecy.

The British, who were depending heavily on American equipment for their part of the radar jamming operation, found themselves short of men familiar enough with the United States gear to do a good job of installing and testing it. Therefore, NDRC and United States Service civilian engineers assisted the British in the installation of the American countermeasures equipment. These engineers were divided up among half a dozen British Naval bases, and by D-day, 90 percent of the proposed installations had been completed satisfactorily.

The invasion really began with the Air Force attack on the German radar sites. This took place shortly before D-day, and in order to avoid betraying the location of the coming attack, radars had to be put out of action along virtually the entire channel coast. Rockets punched out nice round holes in parabolic antennas and in transmitter huts, and 50-caliber machine gun bullets played havoc with the delicate equipment.

Yet in spite of this tremendous dressing down, when the invasion actually started, a certain portion of the radars were observed to be still on the air. The night before D-day, airplanes carrying jammers cruised up and down England's south coast and jammed the German long-range early warning radars so that the Germans were prevented from seeing our air squadrons forming over England, and approaching the continent.

Early in the morning of D-day, a small force of bombers flew a jamming and Window diversion inland from the Dover-Calais area in an effort to simulate a large bombing raid headed for Germany; many enemy fighters are known to have taken this bait, and to have spent much of the night circling fruitlessly inland near Calais to the east of the main invasion forces. With the aid of air diversions intended to simulate additional air-borne landings, our American air-borne troops were able to complete their landings on the Cherbourg peninsula with very little opposition, and with phenomenally low losses—one-half of 1 percent. The diversions provided a good part of the answer to a question almost universally raised at the time of the invasion as to the whereabouts of the *Luftwaffe*.

Naval diversionary forces from Folkstone approached the French coast just south of Calais; other forces from Newhaven crossed the channel south of Dieppe. Aircraft flying low over these ships dropped enormous quantities of Window in order to supplement the increase in ship "size" provided by special reflectors. The additional Window made the separate ships look like one huge convoy.

The Royal Navy sent a group of plucky HDML's—Harbor Defense Motor Launches—out on a screening mission, during which they spent some hours off the French coast north of Normandy. These craft, plying their countermeasures vigorously in an effort to seem like a major fleet, had the satisfaction of drawing a considerable amount of inaccurate German gunfire.

A United States cruiser—one of the ships which had not received its quota of jamming equipment—found itself the target of accurate gunfire while standing far offshore. In view of the distance involved, the fire was obviously radar-controlled. The Naval Task Force Commander then ordered that this ship change positions with one fitted with the latest jamming transmitters. As soon as the swap had taken place, the shore fire became inaccurate, and soon stopped altogether.

The Germans later attributed much of the success of the invasion to their inability to meet the landing forces with all the reserves at their disposal. Certainly the confusion was considerable. The German radio announced on several occasions during the operation that landings had been repulsed at points where they had not, in fact, been attempted. One enemy radar operator, whose set commanded Omaha beach, told interrogators that he had known something was coming, but had had no idea what it was.

The invasion of southern France followed much the same pattern as the Normandy operation, only this time it was primarily an American show. The good work done by the radar-hunting Ferrets in the Mediterranean theater paid off during "Operation Anvil," even though the harrassed German operators had been forced into foxy tactics, such as not tracking single planes at night, and pulling in special retractable radar antennas when photo-reconnaissance planes were about by day. The Germans had reason to fear our radar reconnaissance, for prior to the invasion itself, some 500 air attacks were made on 22 known enemy radar sites.

The Navy part of the invasion included a main force, a support force, and two diversions. Radar countermeasures received considerable attention in the diversionary forces, for the attack was purposely planned to begin under cover of darkness, in order that the enemy might not discover the nature and scope of the operation until it was well under way. Countermeasures equipment were installed in about half that number of British and American ships ranging from landing craft to cruisers.

The air-borne portion of this show was also protected by diversions using Window and by planes fitted with electronic jammers. To add further to the confusion, a ground-based Signal Corps radar jamming and intercept installation located in Corsica also joined in the chorus. This outfit, located on a mountain top at the northern end of the island, had for months been carrying out a round-the-clock study of the intimate habits of the German radars dotting the southern French coast. From this study, much valuable information had been obtained on the German tactics.

As was the case in Normandy, interrogations afterward showed that our countermeasures had been successful. The vaunted radar ramparts of Fortress Europe had not only been rendered useless to the Germans, they had been rendered worse than useless, for when needed most, they had become a source of completely misleading information.

5 (e). *Electronic Ears To Go With Radar Eyes*

As was pointed out earlier in this account, radars send out very strong radio signals which can be picked up at considerable distances by means of a suitable radio receiver. Just to be able to hear a signal, however, is seldom enough, since the question, "Is there a radar there?", is usually followed immediately by "Where is that radar?".

As we have seen, this problem first became serious in connection with the Sicilian campaign and the business of plotting German coastal radars that might be dangerous to our invasion forces. The experience of those early days was well applied at home in speeding research on aircraft direction finding systems which did not depend on a change of aircraft heading for their successful operation.

In the end, a very excellent device of this sort was developed. Not only did it tell you direction, but it also told you this direction instantaneously and automatically.

This was done by taking advantage of the fact that for radar frequencies, a directional antenna—i. e., one which can only pick up signals coming from one particular direction—can be built in very compact form. If one of these antennas is made to rotate so that it scans the horizon, signals from a distant radar will be heard only when the antenna is pointing directly toward it. Although the antenna could be rotated by hand, and its heading noted when a signal was received, this is awkward, and it is much better to drive the antenna continuously with a motor and display the received signals (if any) on something very similar to a radar scope. The signals show up on this scope as radial deflections outward from the center of the tube. A signal, looking something like a spoke in a wheel, points toward the target's bearing. The exact direction away from center is controlled by the instantaneous position of the pickup antenna. When the deflection of the scope trace points vertically from the center to the top of the tube, the received signal is coming from dead ahead; if the trace is horizontal and to the right, the radar is on the starboard side, and so forth.

In the fall of 1943, intelligence reports contained disturbing news. The indication was that German submarines were being fitted with a new and considerably improved radar. A high-performance set of this type could constitute a very serious threat to our own radar-equipped search planes which had driven the U-boats down and which had helped to break the back of Doenitz's undersea campaign. If the submarine could see an approaching plane, it would then have ample time in which to submerge to a safe depth. Our planes would still be able to force the subs down, but the enemy radar could remove the element of surprise and thus prevent our planes from making kills.

The Navy was very much interested in air-borne radar search equipment capable of operating in the frequency range understood to be used by the German sub radar. The new direction finder under development at an NDRC laboratory seemed to provide an ideal answer. It was felt that submarine radar transmissions might be intermittent; hence, any device which displayed the direction of a signal instantaneously on a cathode ray tube in much the same manner as a radar displays its echoes seemed to fit the requirements perfectly. This the new direction finder could easily do.

In September 1943, a laboratory prototype direction finder was installed aboard a Navy sea-search PB4Y-1 patrol bomber on the very highest priority.

One month later, the PB4Y1 left for a base in North Africa, from which place it flew over 500 hours in submarine searches over the U-boat hunting grounds in the Bay of Biscay and in the Mediterranean.

Throughout many long and tedious flights the equipment functioned perfectly—but no enemy signals were heard. Back home, anxiety over the supposed submarine radar menace subsided. It appeared that the new German radar was either no good or was not being used.

At the end of the war, the correctness of the latter conclusion was verified. Interrogations of captured submarine crews revealed that the U-boat skippers were downright afraid to turn on their equipment. By preference, the German radar was used only in regions close to the homeland, and then only for navigation in narrow passages. Out in the open ocean, it was almost never used.

This German fear of being overheard could be interpreted as a tribute to our radar countermeasures organization—a tribute which was perhaps not quite justified at the time. However, the fact remains that countermeasures—or the threat of countermeasures—prevented the German U-boat commanders from making use of their radar—a weapon which has made our own submarines many times more effective.

A number of other prototype direction finders were built on a rush basis and turned over to the Navy for air-borne operational use in the Pacific.

On one occasion, one of the Navy's radar-direction-finder-equipped bombers was on patrol in the neighborhood of a crippled United States submarine being shepherded back to its base by two others. The weather was overcast and the visibility poor. Suddenly the countermeasures officer called his skipper on the interphone and reported that he had picked up what was unmistakeably the signal of a Jap radar-equipped plane. He reported the bearing of the enemy aircraft to the skipper.

The skipper immediately headed the patrol bomber in that direction. As they flew along, the signal picked up by the countermeasures operator grew louder and louder, and presently he advised the skipper that they must be closing in on the Jap plane. At that very instant, the radar operator reported contact with an unidentified aircraft, and the patrol bomber was soon maneuvered into attack position.

Nosing down through the overcast, the patrol bomber broke out of the clouds and found a Jap plane directly beneath it. The Betty jettisoned his depth charges and tried to escape, but was soon splashed—only 8 miles away from the United States submarines.

The need for long range patrol aircraft capable of carrying out both radar and radar intercept searches was recognized early in the war by the Navy. The first plane expressly designed for this purpose was the PB4Y2. Known as the Consolidated "Privateer," this aircraft consisted of a single-tailed B–24 whose fuselage had been extended in the nose section by some 7 feet. The extra space thus made available was shared equally by the latest in radar, long-range radio communications, and radar countermeasures equipment, including direction finders. Enough antennas were installed in each PB4Y2 to permit radar intercept work at all frequencies which might possibly be encountered. So many of these plastic-dome-covered antennas were provided, that the prototype "Privateer" was nicknamed the "Warthog."

Space, power, and antenna facilities were provided in the electronics compartment for a flexible installation of search receivers as well as jamming transmitters. For the first time, a coordinated countermeasures installation had been designed as an integral part of an airplane.

NDRC engineers, working in cooperation with the Navy, took an active part in the planning of the PB4Y2 installation from the very earliest days. Newly developed laboratory equipment was installed in a prototype plane and its performance studied under actual flight conditions.

PB4Y2 planes, of which some 600 were ordered at one time, were playing an active part in Pacific operations at the conclusion of the war. The first to arrive in that theater operated out of the Naval base at Manus in the Admiralty Islands in February 1945. A substantial number were on duty in the Philippine area by March.

A ship-borne version of the radar direction finder was developed shortly after the air-borne model. During the course of its first trial run aboard a destroyer escort, the remarkable capabilities of this equipment were clearly demonstrated. During maneuvers off shore, the radar operator of the DE made contact with a target at a certain range and bearing. The countermeasures operator, meanwhile, picked up a number of different signals all coming from the same bearing. From the characteristics of these signals, as well as from the frequencies at which they were tuned in, he deduced that the vessel on the bearing in question must have been a United States cruiser. When this information was reported by him to the bridge, the captain's amazement was profound. That gentleman must have decided the advantages of radar were now complete: not only could these electronic devices tell the range and bearing of a target, but now they could identify the nature of the target as well.

5 (f). Fleet Radar Countermeasures

In Europe, special teams of countermeasures experts who were used for the execution of the antiradar phases of amphibious operations, since these were not numerous or separated by vast distances. The Pacific theater, however, presented Navy planners with an entirely different problem in logistics.

Not just a few but many landing operations were in the cards. Moreover, the timing of these events was such that they had to be planned and rehearsed many months in advance, thus permitting prompt execution at locations widely separated from each other. Teams of experts could not be moved from place to place fast enough to keep up with the parade of D-days. For these reasons, a bold decision was made: radar countermeasures would be made a Fleet-wide activity rather than an electronic specialty. Radar officers became electronics officers; in addition to their other accomplishments, they became experts in radar countermeasures.

This decision resulted in an extensive installation program, designed to make every combat ship in the Fleet self-protecting from an countermeasures point of view. Ships from destroyer-size on up, carried both intercept and jamming equipment; now countermeasures antennas sprouted on masts and yardarms like mushrooms.

Even landing craft had their complement of the new equipment. Every effort was made to protect these vulnerable ships from radar-aided aerial attack or radar-controlled shore fire. Pretuned, unattended jammers installed aboard the landing ships were arranged to play havoc with any Jap radar which might be encountered.

Careful plans were made to coordinate the operational use of the Fleet-wide installations. Special communications channels were set aside for the use of operators reporting enemy radar intercepts. This information, like the data supplied by our own radars, was fed into the CIC, or Combat Information Center, of each ship. There it was found that radar and countermeasures data supplemented each other perfectly. If on the same bearing an enemy radar signal was heard, and an unidentified radar contact reported, there was little doubt as to the nature of the "bogey" or unknown target. On the other hand, if a friendly radar signal was heard coming from the direction of an unknown target, it was a good idea to hold back fire and investigate a little further.

The logging and checking of Allied radar signals represented an important function of the countermeasures intercept equipment. Oftentimes intercept operators could detect troubles in radars of their own task force even before those troubles became apparent to the radar operators themselves.

Radar intercept work in our surface ships was begun in the fall of 1943 during attacks on the Marshall Islands. The Jap radars, kept under surveillance at that time, were actively taken into account during the next operation at Palau. Plans were made, and equipments were ready, in case the Jap radar presented a real threat.

Considerable radar reconnaissance preceded the Marianas operations. An approach lane was plotted, through which our forces could slip without fear of detection by enemy radar.

The preinvasion bombardments of Iwo Jima were carried out by cruiser task forces which relied heavily on radar intercept gear during their approach to the target. In order to prevent being detected themselves, the cruisers "secured"—that is, turned off—much of their low frequency radar which might conceivably be intercepted by the Japs. By listening to Jap shore radars, the cruisers were able to tell if they had been detected by the enemy. As long as the Jap radars swept aimlessly back and forth, our forces knew no warning had been given.

During the actual landings, countermeasures intercept and jamming activities were coordinated by a control officer stationed in the amphibious force commander's flagship. As soon as an enemy threat appeared, this officer was empowered to rearrange the available countermeasures in order to meet it.

The Japs were much behind the Germans in electronic developments. However, as the Pacific campaign developed and our surface forces approached closer and closer to the mainland of Japan, a new form of Japanese radar put in its appearance—a radar potentially very dangerous to our Naval task forces. This equipment consisted of a crude but effective air-borne search set patterned after the original British equipment which did yoeman service in 1941. This gear was mounted in a number of different kinds of Jap aircraft, ranging from their long-range patrol ships to their torpedo bombers.

Aided by their new radar, the Japs did, in fact, succeed in locating our forces with greater ease. The most common procedure consisted of sending out a "snooper" plane which would intermittently shadow our ships, taking care—out of a healthy respect for our task force air patrols—to come no closer than the greatest distance at which it could establish radar contact. If the Japanese then elected to launch a full-scale air attack, the snooper would radio instructions to the attacking aircraft, thus enabling them to find the position of the American task force without difficulty. Few of the planes actually pressing home the attacks were equipped with radar, although often a single radar-equipped plane would lead several others in.

The Japs never perfected the radar-aided torpedo attack as did the American Naval forces with the aid of their superior equipment. However, they were able by means of radar to bring their planes into fairly close range from which point the attacks could be carried on visually. Flares were often used at night.

By November 1944, when the Jap air attacks began to assume some importance after the introduction of suicide tactics, the United States Navy was well equipped with radar search and intercept equipment, much of which had been developed jointly by the NDRC and by Service laboratories earlier in the war.

In general, radar intercept equipment was manned on a 24-hour-a-day basis when there was fear of Jap air attack. The particular frequency ranges in which the Jap sets were known to operate were closely scrutinized.

The radar search equipment would usually intercept the signals of an approaching Jap torpedo plane as much as half an hour before that plane itself was able to detect the presence of the American forces. Moreover, the signals would also be heard many minutes before the powerful United States Fleet radars could pick up the approaching enemy. Often the first warning our Naval forces had of the approach of hostile aircraft was the tell-tale indication picked up by the countermeasures operator.

By listening to these signals, a skilled operator could almost read the enemy pilot's mind. Wearing a pair of earphones, or watching a scope much like a radar's, this man would spend his time tuning his receiver back and forth on the lookout for new transmissions amid the welter or familiar radio signals from ships and planes of his own task force. There was no mistaking the sound of an enemy radar signal: that high-pointed whine meant only one thing: Jap air attack. At first, these tones would be weak and wavery: that meant the Jap was still searching from side to side looking for our task force; if the signal grew strong and steady, that meant look out for trouble—he's found his target.

Often it was possible, on the basis of countermeasures information alone, to send out a night fighter in the proper direction in advance so that the final interception by means of radar could be speeded up. The best trick of all was to shoot the enemy down before he had located the task force. This could be done because our ship radars outranged the snoopers. It was not easy to do, but the effect on

Jap morale was very satisfying. The extra warning provided by the countermeasures gear was invaluable.

Countermeasures operators not only could tell that enemy planes were approaching, but also could give the direction from which to expect the attack. This information enabled interceptors to find their targets sooner, and also helped the ships' radars to pick up the enemy more quickly by telling them the direction in which to look.

As the Pacific war approached a climax, the tactics of the United States Naval task forces grew more and more daring. On many occasions our carriers cruised for several days in the vicinity of Japanese-held territory, and no longer depended on their speed to keep them out of danger. During that period a serious threat to our operations was the Jap night torpedo bomber, especially the kamikaze version. It was important to deny them the benefit of radar.

When these radar-aided attacks first became serious, it was found that the frequency used by the Japs could not be reached by the tubes used in existing shipboard jammers. Representatives of the Navy turned to an NDRC industrial laboratory in October 1944 with an urgent request for a tube that would do the job. Fifty were needed, and 1 week was the time limit.

Experiments performed in the laboratories that very day showed that the design of the tubes previously used could be modified to accomplish the purpose. Instructions were given to the manufacturing department, and the tubes were delivered in time. Not long afterward, as a result of remarkable teamwork all down the line, the new tubes were in successful operation.

When jammed, the Jap radar-equipped planes reacted very definitely. An approaching enemy bomber, guided by radar, could be tracked as it came in by our ships' own radars. When the Jap came close enough to show clearly which ship he had chosen for a victim, the countermeasures operators on that ship would turn on their jammer. Robbed of his radar, the Jap pilot usually gave up and went home. Operators on our ships, watching the enemy bomber on their radar scopes, had the satisfaction of seeing the enemy waver and finally turn back.

Many grateful skippers authorized their countermeasures operators to paint a Jap flag on their jamming transmitters after each successful action.

5 (g). Superforts and "Porcupines"

By the time our Pacific Air Forces had begun to mount relatively heavy attacks against the Japanese home islands, the Jap air defense system included reasonable effective searchlight control and antiaircraft fire control radars. One of these radars was based on an early

United States set captured in the Philippines; another on British equipment captured at Singapore. Both sets had already been encountered in Formosa and in the Manila area. In both these places they had, in fact, already been jammed. Sample fire control radars had even been captured and shipped to the United States for analysis.

However, before the B-29's began their raids on heavily defended targets in Japan itself, few opportunities had presented themselves for investigating the antiaircraft defense systems of these objectives. It was felt that the best Jap equipment would probably be hoarded for a last-ditch fight. The number of these sets, their deployment, and their method of use against day and night attacks by America's newest and most effective bombardment aircraft, were unknown quantities.

One of the better ways to get this type of information is to carry radar intercept equipment in the aircraft participating in the strikes. The Jap radars had always displayed a considerable degree of nervousness when plotting single planes; they showed an understandable but irritating tendency not to turn on all their available equipment until a full scale attack was in progress.

In anticipation of this strategy, provision had been made for the optional installation of intercept and jamming equipment in all production Superforts. Space was reserved and power facilities provided in each plane. In actual practice, two or three planes of a group scheduled to take part in a mission would be selected to carry radar intercept receivers operated by AAF countermeasures officers.

During the course of their strikes over Japan, the B–29's soon began to encounter uncomfortably accurate flak through dense clouds, and effective enemy searchlight control at night. The countermeasures search planes, by correlating signals heard to accurate Jap fire, showed plainly that radar was responsible for the Jap blind fire control. Moreover antiaircraft sets in considerable numbers were discovered. As a clearer picture was gained of their employment by the enemy, plans for appropriate counteraction were made.

Early in April 1945 when the Mariannas-based B–29's were flying 500-plane raids, a full-scale jamming program was undertaken. By the time the war ended, every Superfort carried at least 1 jammer, some carried 2, and operational plans called for the installation of 2 jammers in every B–29 delivered to the Pacific theater. Simultaneously, the B–29's started the large scale use of a new form of Window, called "Rope." Instead of many short strips of foil, Rope consists of 400-foot aluminum foil ribbons suspended from parachutes. This countermeasure proved to be especially effective against low frequency radar like that employed by the Japs. The protection provided was considered so important that ultimately nearly 600 pounds of aluminum foil in the form of rope were to be carried in every B–29 on every mission.

On daylight raids, the B–29's flew in close formation, for mutual protection and better bombing accuracy. Under these conditions, a single jammer in one plane can protect all the other planes in the group against an enemy radar. If each plane carried a jammer, there would always be a safe margin of jammers over enemy radars within range of the formation.

At night, the problem was entirely different. The B–29's flew in very long, loose formations, with approximately a mile between aircraft. Under those conditions, each plane could only hope to protect its immediate neighbors. While it was theoretically possible for every bomber to carry enough jammers to screen itself from all the radars which might be encountered, the weight of equipment required made this arrangement uneconomical.

It was decided instead to fit out a few special jamming aircraft whose sole job would be to cruise around in the target area and jam any radars which might come on the air during an attack. This was technically possible because the Jap low frequency radars had broad beams which could be jammed from any point in a wide area.

These B–29's, which carried in place of a bomb load as many as 18 jammers, as well as the necessary receivers and operators, were nicknamed "Porcupines" because of the many spinelike antennas projecting from their fuselages. Their task, during attacks, was to fly over the target area along a course parallel to the bomber stream and at an altitude somewhat above it. In this manner the Porcupines stayed out of harm's way while protecting the main bomber force. Again, it was a battle of wits between the men in the jamming planes and the radar operators on the ground below. The Japs lost.

5 (*h*). *How To Heckle the Japs*

ALTHOUGH OUR high-altitude strategic bombers in the Pacific played a very important part in the campaign against the Japanese, much of the pin-point bombing was carried out at medium altitude by carrier planes of the United States Navy. During invasions, particularly those at Iwo Jima and Okinawa, it was necessary for our carriers to come in close to shore for extended periods in order to give our beachheads continuous support. These valuable ships presented all too vulnerable targets to Jap land-based planes. To protect them, as well as the invasion forces, all Jap air fields within range had to be kept under continuous attack. This was done both day and night by planes based on our carriers.

The procedure usually consisted of sending out two or three aircraft—normally two fighters and a torpedo plane—to each airfield.

These planes would then maintain a continuous patrol, and if any signs of activity developed on the ground below, one or more of them would go down and shoot things up a bit. However, the Japs, aware of the importance of their airfields, had not failed to concentrate antiaircraft defenses in their vicinity. At night, our hecklers encountered accurate searchlight control and antiaircraft fire.

To cut down this particular hazard, encountered in the course of an all too hazardous job, our carrier hecklers were given radar countermeasures protection. Jamming transmitters were installed in each torpedo plane and its radio operator doubled in countermeasures. The Pacific variety of Window known as "Rope" was also provided in considerable quantity.

This improved the night hecklers' sport. Not only could they shoot up all sign of life below, but they could now jam the Jap radars off the air as well. On many occasions when the jamming came on, the Japs actually shut down their equipment, presumably to find out what was the matter with it. They thought it curious that so many of their honorable radars should give trouble at once.

The Rope was equally successful. It is an unpleasant feeling—and unhealthy—when flying along at night, to be caught without warning in the glare of a number of searchlights. When a plane is properly "coned" it is virtually impossible to shake off the lights unless there is a cloud nearby to hide in. Our Navy airmen on these occasions, put their planes into a dive, tossed out some of the magic bundles of Rope, and had the satisfaction of seeing the Jap radar-direct-searchlights follow the Rope, which was soon left far behind.

The night "hecklers" were not the only carrier aircraft to receive radar countermeasures protection. During raids over heavily defended targets—such as those in Hongkong, Formosa, and Japan itself—Naval aircraft were almost universally supplied with Window or Rope, and the larger planes also carried jammers. In some instances, automatic Window dispensing machines were installed in fighters in order to relieve the already overburdened pilot from the chore of throwing out packets by hand.

5. (*i*). *Ferrets and Black Cats*

By reason of the nature and geography of the war in the Pacific, radar might have been an extremely effective defensive weapon for the Japanese. That it was not, is due to two reasons—first the slow development of Jap radar, and second the timely application of radar countermeasures by the Allies.

Because, in the island warfare of the Pacific, our planes had to fly long missions—many of them as long as 18 hours—the extra gas required meant fewer bombs. It also meant fewer evasive detours from the straight line that is the shortest distance between home base and the target. A few radar sets, strategically located on small Jap-controlled islands, could serve to alert the enemy and assure our bombers a hot reception.

Moreover, our bombers in this theater flew until very late in the war, without benefit of fighter protection. There was no attitude of "let 'em come up so we can shoot 'em down" as in Europe.

Much of the South Pacific war was an antishipping war—a struggle to cut the Jap supply lines. An important part was the mining of harbors to rob the Japs of safe anchorage—a hazardous task which was largely done by planes at night.

Because of the long missions over water, air-sea rescue work had to be assigned a high priority. Many daring rescues were carried out by patrol planes, also operating at night.

All these activites could be seriously hampered if the Japs were allowed to have full use of their radar. The importance of countermeasures was emphasized.

Army B-24 "Ferret" planes, Navy day and night patrol aircraft, and Fleet submarines were given the assignment of locating enemy radars. (Navy Catalina Flying boats were nicknamed "Black Cats" because of their black paint and nocturnal habits.) These mobile listening posts spotted and pin-pointed Nipponese air warning sets scattered all the way from the Solomons to the China coast and sited at virtually every strong point.

Maps showing the probable coverage of these enemy equipments were drawn up and supplied to the operating forces. This meant that aircraft missions could be planned to avoid detection by radar (when a choice of courses was available). For example, the night mining of the heavily-defended Balikpapan harbor was carried out with the aid of these maps by aircraft based in Australia. In the event that the course could not be changed, and only one or two radars presented a threat, they would be put out of action by bombing and strafing planes known as "radar busters." Some of these planes themselves were fitted with countermeasures equipment which enabled them to "home" on radar signals, thus using the enemy radars as navigational beacons.

In some cases more drastic action was necessary. A few days before the Leyte landing in October 1944, one of the Ferret planes discovered a new Jap radar which proved to be located on Suluan Island, at the mouth of the Leyte Gulf. This set commanded the approaches to the very strip of Leyte coastline on which we were to land, and it was absolutely essential that the Japs be deprived of its use. This unfortunate radar and its crew were eliminated by United States Rangers in a neatly executed Commando raid. As an incidental, several other radars on Mindanao were also demolished in order to prevent the Japs from inferring that we had our eye on Leyte Gulf.

When enemy radars were too numerous to be "busted," the Ferrets and Cats were called upon to do some jamming in addition to their normal duties. In one case a Cat accompanied a group of low-flying mine-laying planes into Manila Bay on an operation considered certain suicide for all. The judicious use of jamming transmitters, coupled with the dropping of "Rope," so confused the Jap radar defenses that many of the stations went off the air, guns were fired wildly, and the attacking planes were able to complete their mission without a scratch.

Radar search receivers were installed on our submarines as soon as satisfactory sets became available. Seldom has the introduction of a new equipment been greeted with as much enthusiasm by the operating crews. Use of the new receiving gear was immediately made a part of each submarine's operating plan. The skippers swore by radar countermeasures, and it was not long before every sub that could carry the new gear had received its quota, for it played an important part in every phase of submarine operations.

Our subs were given the job of scouting the enemy in addition to their offensive mission against Jap shipping. Surfacing at night deep in enemy waters, our undersea craft took time to study Jap radar defenses, learning not only what sets the enemy had, but where he placed them. The information brought back was distributed to all fleet units, thus forewarning countermeasures operators of new enemy signals and frequencies.

During the first part of the sub attack on Jap shipping, enemy vessels were plentiful and easily found. As operations successfully continued, an understandable scarcity of targets resulted. However, the Japs, fearful of unpleasant surprise attacks, began to equip their vessels with radar to give warning of United States air or surface attack. These radar signals, of course, were easily detected; our subs, attracted by the Jap transmissions, could turn off their own radars to silently move in for the kill. In many instances, the Japs were returned to their ancestors without knowing what had given them away.

Jap submarines were given radar—a crude air search set not very good at detecting surface targets. During one classic patrol, a United States submarine commander located three Jap subs in succession by means of their radar transmissions: in each case, he followed the signals in until they abruptly ended—silenced by United States torpedoes. For this remarkable performance, the United States skipper and his crew were given a citation in which radar countermeasures were credited with a direct "assist."

When Jap aircraft were fitted with radar "eyes" with which to see at night, our submarines were prepared. A strict watch was kept on the enemy wave lengths, and all signals noted. Should a wavering tone steady down and begin to increase in strength—a sure sign the enemy had detected you—our subs would leisurely switch on their own radar just to check the range, and then prepare to dive. They had ample warning, for the enemy could be heard even before he could be detected by the sub's own radar. Moreover, our subs were not obliged to advertise their presence by continuously operating their radars—they could depend on their electronic ears to avoid detection at night.

5 (*j*). *Tuba and the German Night Fighters*

One of the most ingenious countermeasures developments of the war was a device known as "Tuba"—a tremendously powerful jamming transmitter developed for use against German night fighters. In addition to its countermeasures application, "Tuba" has interesting peacetime applications. It was certainly one of the outstanding individual scientific achievements of the war.

The problem was to create a jamming device to blind the German night fighters, which in 1942 took a heavy toll of British night bombers. The German fighters used an air-borne interception radar known as "Lichtenstein" for close-range location of their targets. Against them the British found it impractical to use jammers carried in their bombers, because the jammer itself provided a signal which the German fighters could use to locate the bomber. A radio signal, including a jamming one, betrays the direction from which it comes, and even though a jammer might blot out a German scope, making it impossible to find the range, the German could find the bomber simply by following the signal in.

But the German night fighters usually did not reach their prey until after the British bombers were flying home from their mission. Someone suggested, why not set up a very high-powered jammer in England to blind the German fighters' radar as they flew toward it in pursuit of the homeward bound bombers? It would be a blinding beam—"shining" in the German "eyes" (i. e., their radar antennas)—through which the bombers could fly to their bases in safety.

A jammer of this sort obviously would require enormous power. It was calculated that it would need power a thousandfold more than any previously attained in the frequency range of operation involved, which in itself was 10 times higher than that used for frequency modulation and television.

It appeared possible to solve the power problem by means of a very remarkable vacuum tube, developed in the United States, known as the "resnatron." This NDRC development, sponsored by the Signal

Corps, was so promising that the British forthwith placed a lend-lease order in the United States for a complete jamming system based on its use.

Since the experimental model used a huge parabolic antenna, the project was promptly nick-named "Tuba," to distinguish it from smaller projects already known as "Piccolo," "Flute," and the like.

All sorts of difficult technical problems had to be solved. It was necessary to build a resnatron that would be tunable over a wide frequency range (because the Germans could change the frequency of their radars by slight modifications). This had been thought incompatible with high power, but a tunable resnatron was produced in one of the industrial laboratories. Also it was necessary to find a way to modulate the resnatron's output with the random "noise" necessary for jamming, but this too was accomplished and by January 1944 a workable instrument had passed its test.

Its power was comparable with that of the most powerful United States broadcasting station (50,000 watts), yet the frequency of operation was 500 times as high. The whole instrument, together with all its associated equipment and its primary power generator, was loaded in seven Army trucks.

By June 1944, the complete jamming system had been shipped to England and was in operation against the enemy—a remarkable achievement when one considers that the equipment was still in the blueprint stage when work began early in 1943, NORC scientists were flown to Great Britain to help set up the equipment and train the RAF in its use.

It is now known that in June 1944, the Germans changed over to an entirely different type of night-fighter radar. If there was any doubt in their minds as to the desirability of making the shift, the first blast from Tuba must have convinced them. The British were profoundly satisfied with the project, and ordered two more equipments in addition to the first.

The power output developed by Tuba is of such unforeseen magnitude that our planning for frequency channel allocations in the ultra-high-frequency range will be directly affected. Tuba, by raising the sights on what is possible, has made existing thinking obsolete, and will tremendously advance the development of ultra-high-frequency broadcasting.

6. Epilogue

Special Problems Encountered

To GIVE a better understanding of what is involved in a countermeasures development, let us trace a particular device from its inception to its final operational use.

First, it is necessary to find out not only that the enemy has a new electronic equipment, but also its exact nature. Based on this, engineers propose a possible countermeasure. This device must then be built in the laboratory and its feasibility tested against some equipment which is a reasonable facsimile of the enemy gear. If the equipment passes these tests, it is then necessary to consider its use in relation not only to operations currently being carried out in the theaters of war, but to those operations which will be in progress by the time the new countermeasure can be manufactured and introduced on a wide scale.

Once the decision is made to manufacture the device, a manufacturer is brought in, an order placed, a model built. This model is tested by the Army or Navy to determine its ruggedness and suitability; regular production is then begun. The equipments, together with all necessary accessories, must be shipped to an operating theater; the forces must be trained in its use, and operational plans or tactics devised or modified accordingly. Finally, the results obtained by the use of the countermeasure must be assessed by operational research of various kinds.

Countermeasures research and development was carried out in Navy, Army, and NDRC laboratories. These laboratories were supplied with information on the latest enemy electronic developments through Service intelligence channels. In many cases, entire enemy equipments were picked up by field intelligence teams and shipped to United States Service laboratories where they were pieced together and placed in operating condition.

The information thus gained on the performance and vulnerability of these equipments was often invaluable.

As an example, a Jap air-borne radar captured at Hollandia, New Guinea, was shipped to a Navy laboratory in the States, reconditioned, mounted in a United States airplane, and returned to the Fleet at Pearl Harbor, arriving there in time to participate in a full-scale rehearsal of the Iwo Jima landing operation. Shipboard countermeasures operators thus got the best possible training—they learned in advance not only the characteristics of the enemy radar signal, but also the details of the performance of the radar itself.

The Army Air Forces maintained a field proving ground in the United States at which captured enemy radars were set up and their weak points determined. One of the German antiaircraft fire-control radars, reconditioned by Signal Corps experts, was set up at this radio research proving ground. The latest in countermeasures was tried out against the latest in enemy equipment.

In the field of radar countermeasures, the Services have been aided in various ways by NDRC assistance. This has not been confined to laboratory research and development along; special arrangements have been made to assure manufacturers a maximum of service from the developing agency in order to keep the time required for bringing a new device into production at a minimum. After the production equipment arrives in the field, the problem of fitting it in planes and ships in the available time between operations and other duties is not easily solved. Training of operating and maintenance personnel must also be carried out with dispatch. To help in these phases of countermeasures work, civilian engineers have been sent to almost everyone of the fighting fronts.

As countermeasures equipment was perfected it was necessary also to develop a full line of new electron tubes, of which the resnatron, mentioned in the previous section, was only one. Although very short radio waves, of high frequency, had been produced in the early stages of the radio art, most of the work with high power had been done on much longer waves. Because of the fact that the short ones can more easily be focused into a beam they had been applied more and more in radar and consequently, countermeasures equipment had to operate with waves of the same size. Many new tubes had been devised for radar, but these worked by pulsing—that is, in a short burst of about a millionth of a second, followed by a much longer rest period. Tubes for jamming had to produce their power continuously, so the requirements were much more severe. This work, the designing of such tubes, was performed mainly in industrial laboratories. Much of it was carried out in advance of actual Service requirements.

One of the most important tubes in this work was the magnetron. Before the NDRC research program was started, however, there were no magnetrons in existence which could supply the necessary power at the required frequencies. At the end of the war, as a result of industrial research for the NDRC, there was a complete line of magnetrons of high power covering a wide range of frequencies.

Although radar was one of the most important electronic weapons of the war, there were others that made use of radio and electronic principles, and which were also susceptible to countermeasures.

Postwar Possibilities

There has been a steady trend, in past radio development work, in the direction of higher and higher frequencies. First came broadcast radio, then short-wave radio and finally FM. This trend has been enormously accelerated during the war by the need for radar and allied devices. However, much of the radar technique—such as the pulse-echo method itself—is highly specialized. Countermeasures development work, on the other hand, has been concerned with continuous-wave techniques similar to those used in ordinary radio communication.

The new developments embodied in the design of countermeasures equipment represent the very developments which will be needed to solve many postwar problems and to make possible many postwar developments.

Basically, much countermeasures research was directed toward the improving and developing of radio transmitters and receivers of a type very similar to those which will be used in postwar FM, television, and radio relay transmission.

U. S. GOVERNMENT PRINTING OFFICE : O—1951

For sale by the Superintendent of Documents, U. S. Government Printing Office
Washington 25, D. C. - Price 20 cents