# United States Army Security Agency
# Training Center and School

**Fort Devens, Massachusetts**

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# INTRODUCTION TO ELECTRONIC WARFARE

## *Section I. GENERAL*

### 1. OBJECTIVES

a. To explain what electronic warfare is.

b. To describe its beginnings and how it has developed.

### 2. INTRODUCTORY INFORMATION

Newton's third law of motion, which states that every action has an equal and contrary reaction, could be paraphrased to describe the history of warfare. Since man first battled with a human enemy, every aggressive action has called forth a defensive reaction, or countermeasure. The caveman who used his club to deflect another caveman's hurled stone -- a skill highly regarded even today -- was employing a countermeasure.

Slingshots, arrows, spears, and swords increased the aggressor's effectiveness. But his adversary devised body armor -- first of leather, then of bronze -- to turn aside these weapons. The longbow and crossbow forced adoption of heavier armor, which withstood the weapons but weighed down the wearer. This worked well as long as opposing forces engaged in hand-to-hand combat or faced each other at a proper distance and exchanged missiles. But when the first practical firearm, the harquebus of the 16th century, was found capable of piercing even the heaviest armor at 200 or 300 yards, the outraged knights abandoned armor in favor of mobility.

In our own century the tank, which combines armor with mobility, gained a significant advantage for the attack. But in World War II, rocket-propelled projectiles, like those fired from the bazooka, countered the tank and at the same time vastly increased the range of offensive weapons.

### ELECTRONIC WARFARE

The military use of electronic devices and techniques to prevent or reduce an enemy's effective use of radiated electromagnetic energy while insuring our own effective use of radiated electromagnetic energy. Electronic warfare is subdivided into electronic countermeasures (ECM) and electronic counter-countermeasures (ECCM).

### ELECTRONIC COUNTERMEASURES[1] (ECM)

That major subdivision of EW involving actions taken to prevent or reduce the effectiveness of enemy equipment and tactics employing or affected by electromagnetic radiations.

#### ACTIVE ECM

The deliberate radiation, reradiation or reflection of electromagnetic signals with the object of impairing the use of electronic devices by the enemy.

##### COMMUNICATIONS JAMMING (COM JAM)

Electronic jamming against any medium using electromagnetic radiation to convey a message from one person or headquarters to another.

##### NONCOMMUNICATIONS JAMMING (NONCOM JAM)

Electronic jamming against electronic devices other than those used as a means of communication. Noncommunication jamming includes but is not limited to –

1. Navigation countermeasures (NAVCM)–Countermeasures against electronic navigational aids.
2. Radar countermeasures (RADCM)–Countermeasures against radar.
3. Controlled devices countermeasures (CDCM)–Countermeasures against guided missiles, pilotless aircraft, proximity fuzes, and similar devices.

#### PASSIVE ECM

The search for electromagnetic radiations to determine the origin and pertinent characteristics of those electromagnetic radiations, which the enemy (or potential enemy) may be using for the purpose of conducting active countermeasures operations. Passive communication countermeasures (search and intercept) is a communication intelligence activity directed specifically toward foreign electromagnetic radiations used for communication purposes.

#### ELECTRONIC DECEPTION

The deliberate radiation, reradiation, alteration, absorption, or reflection of electromagnetic waves in a manner intended to mislead an enemy in the interpretation of data received by his electronic equipment, or to present false indications to his electronic systems. Electronic deception is primarily directed against the enemy electronic surveillance and control systems and his communication intelligence organization. It may be subdivided into communication deception and noncommunication electronic deception and includes –

1. Imitative deception– The intrusion into enemy channels and the introduction of matter which is an imitation of the enemy's electronic radiations for the purpose of deceiving or confusing the enemy or to saturate a portion of his electronic system.
2. Manipulative deception–The use of established friendly means of electronic radiations in such a manner as to falsify the information which an enemy can obtain from intercept and analysis of these radiations.
3. Simulative electronic deception–The creation of normal types of electronic radiation to simulate friendly units, installations, or activities to confuse or deceive the enemy as to the location, strength, or movement of our forces.

### ELECTRONIC COUNTER-COUNTERMEASURES (ECCM)

That major subdivision of EW involving actions taken to insure our own effective use of electromagnetic radiations in spite of the enemy's use of electronic countermeasures. Antijamming refers to the measures taken to nullify or reduce the effect of enemy jamming.

#### CONTROL OF ELECTROMAGNETIC RADIATIONS - (CONELRAD)

Action taken to insure essential services to friendly forces while denying or minimizing the use by the enemy of our electromagnetic radiations as an aid for his navigation or guidance of weapons.

#### TRANSMISSION SECURITY

That component of communication security which results from all measures designed to protect transmissions from interception and traffic analysis.

### RELATED ACTIVITIES

#### COMMUNICATIONS INTELLIGENCE (COMINT)

The technical and intelligence information derived, by other than the intended recipient, through interception and processing of foreign communications passed by radio, wire, or any other electromagnetic means.

#### ELECTRONIC INTELLIGENCE (ELINT)

The technical and intelligence information product of activities engaged in the collection and technical processing for subsequent intelligence purposes of foreign noncommunications electro magnetic radiations emanating from other than nuclear detonations or radioactive sources.

[1] Electronic countermeasures may be further categorized as communications ECM and noncommunications ECM, which are defined as follows:

Communications electronic countermeasures (COM-ECM). A general term used to identify the combination of above means for use against specific targets. COM-ECM includes passive and active electronic countermeasures and electronic deception against electromagnetic radiations used to convey information from one person or headquarters to another.

Noncommunication electronic countermeasures (NONCOM-ECM). A general term used to identify the combination of above means for use against specific targets. NONCOM-ECM includes passive and active electronic countermeasures and electronic deception against electronic devices other than those used as a means of communication.

Figure 1. Electronic warfare definitions and related activities.

Today's accelerated techniques for waging war dwarf all previous offensive and defensive efforts. Since the turn of the century, when Lee De Forrest first experimented with elementary vacuum tubes, man's life and liberty have depended more and more on electricity and electronics. From simple electrical tools and devices of familiar daily use to the complex computers and radars that encircle our nation, we live in an electronic age. Electronics provides the nervous system that controls vast machines and complex equipment for both peace and war. Push-button warfare is no longer fancy, but fact. We push a button and launch an ICBM. We push a button and a vital message speeds around the world. We push a button and a satellite goes into orbit.

But suppose some morning, in actual combat, we were to push a button and nothing performed as it should. Suppose we found all communications so jammed that we could not receive messages, radarscopes so covered with interference that we could obtain no intelligible information from them, and the electronics systems of guided missiles so jammed that their effectiveness was reduced to practically zero.

Any enemy having such power to jam our electronic equipment would have an overwhelming advantage. The result could be catastrophe.

Visualize our forces in action. We are up against a formidable foe; intelligence estimates indicate he is as well equipped as we are. Both adversaries use electronic equipment to see at night and in bad weather, to guide missiles, to aim and fire weapons, to detonate VT fuzes, and to transmit messages. Victory is in the balance.

But suppose we come up with new equipment giving us the ability to jam most, if not all, of the enemy's electronically controlled equipment. This capability alone, properly used in support of a tactical plan, could give us the decisive advantage that would ensure defeat of the enemy force.

Ability to jam the enemy's electronically controlled equipment is included in an area of military activity which we call electronic warfare (EW). Other aspects of electronic warfare are charted and defined in figure 1. The relationships shown in this chart, the terms and their definitions, are the result of an effort to organize a multitude of activities that man has found necessary in the past and will find even more necessary in the future, in order to use and defend his electronic devices. You may find it useful to refer back to this chart as you read of these activities. You will also find a glossary of unfamiliar terms at the end of this information sheet.

All of the following devices used by our military forces are vulnerable to electronic warfare:

Radio -- MF, HF, VHF, UHF, SHF (from .3 mc to 30,000 mc).

Radar -- surveillance, navigational, bombing, target acquisition.

Controlled devices -- rockets, missiles, VT fuzes, drone aircraft.

Infrared.

A characteristic of these devices is the need of each equipment or system to use a specfic portion of the frequency spectrum. But there is only one frequency spectrum, and it is already overcrowded. The modern military requirement for mobility and dispersion has increased military demand for more channels of radio relay and more radios in tactical units. Civilians also must have space in the spectrum. Even our enemies will plan to use it.

Denying our enemies the use of the frequency spectrum is not a new idea. Attempts by one nation to reduce the effectiveness of another nation's electromagnetic devices were made before World War I and have continued with varying degrees of success through World War II and the Cold War. The story of the first radio direction finding and interception in World War I, and the progress made during World War II in active and passive ECM and electronic deception -- the phase Winston Churchill called "The Wizard War" -- constitutes one of the most colorful chapters in military history. Volumes could be written about it. A summary is included here to introduce you to the complexities of electronic warfare by describing the problems of the past and our attempts to solve them; for by analyzing past failures and successes we can better understand and solve the more difficult and urgent EW problems we face today.

## Section II. THE BEGINNINGS OF ELECTRONIC WARFARE

### 3. ESPIONAGE AND ECM

France and Austria-Hungary first recognized the value of intercepting radio transmissions as a means of acquiring political and military intelligence before World War I. For centuries these two nations had cultivated the art of espionage.

In 1908, when a crisis arose with Italy over the Austrian annexation of Bosnia and Herzegovina, the Austrians intercepted and decrypted Italian radio traffic, using the political intelligence so acquired to shape their foreign policy. Three years later, when Italy and Turkey declared war over Tripolitania, the Austrian intercept service proved its value in military intelligence. Between Rome and Tripoli, where they first landed, the Italians had several radio relay stations. This enabled the Austrians to intercept each transmission more than once -- and therefore very completely. Intelligence gained by this service included troop movements from the homeland and day-to-day combat reports from Tripolitania (Libya). It was the first time in history that technical means were used to follow, move by move, the course of a campaign occurring hundreds of miles away.

France monitored all wire lines leading into foreign countries and intercepted foreign diplomatic telegrams before World War I. The climax of this diplomatic intercept was a long telegram to the German Ambassador in Paris from the Foreign Office in Berlin declaring war on France. The French, who had already solved the system in which the message was encrypted, not only intercepted the dispatch, but so garbled its contents before delivery that the German ambassador could at first make nothing of it, while the French gained valuable time.

During World War I the interception of diplomatic traffic was of the gravest importance, and it is interesting to note that for almost three of the war years the British were in possession of the cryptographic system used by the German Foreign Office to communicate with their ambassadors abroad. The secret of this coup was so well kept that the Germans never suspected how vital leaks occurred, and even the United States was not told until the Germans tried, through diplomatic traffic, to involve Mexico in the war by promising them Texas, Arizona, and New Mexico.

### 4. PASSIVE ECM IN WORLD WAR I

Radio Intercept. Before the outbreak of war, both Austria and France set up bureaus to intercept foreign army radio traffic. But it was not until several months after war began that Germany had such an organization. Meanwhile, however, Austria was supplying her ally with intelligence that decisively influenced the course of the German-Russian campaign. The Russians of those early years were incredibly naive about the use of radio. It was still a matter of wonder that information could be transmitted without wires over great distances, and in the Russian Army it was only imperfectly understood that their messages could be heard just as

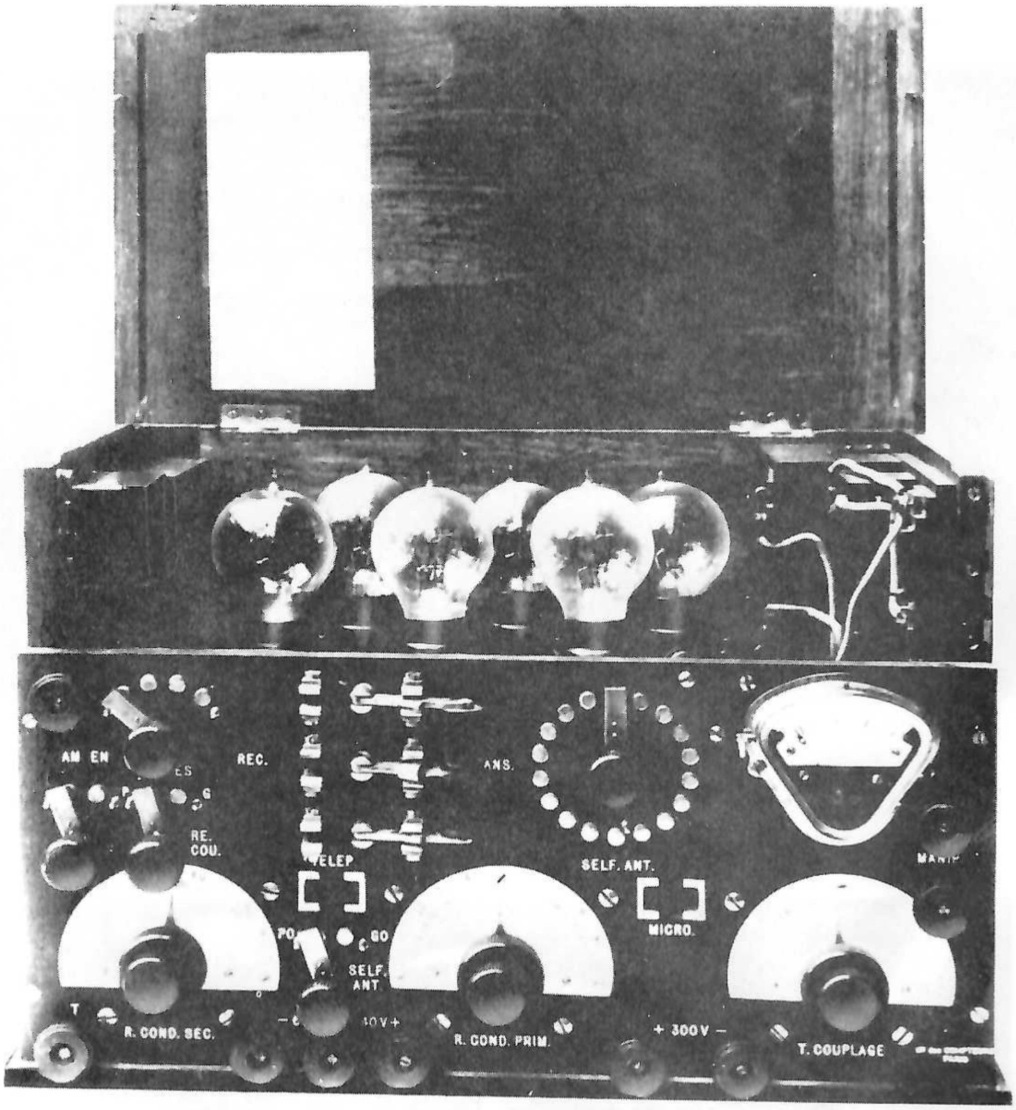


Figure 2. Intercept equipment of World War I: for receiving waves 2,500 to 25.000 meters in length.

well by the enemy. Russian clear text messages, intercepted and forwarded by German operators on their own initiative to General von Hindenburg, helped defeat the Russians at the Battle of Tannenberg. And encrypted Russian messages, intercepted and decrypted by the Austrian intercept service, enabled the Germans to follow Russian movements on the eastern front, day by day and week by week, from the beginning of the war to the close of 1915, when the campaign was decided in favor of the Germans and the groundwork laid for the Russian revolution of 1917.

The Russians afforded the Austrian cryptanalysts wonderful assistance. Although they were always changing ciphers, they often sent the same message in both old and new keys. Or they would send messages in plain text referring to encrypted messages.

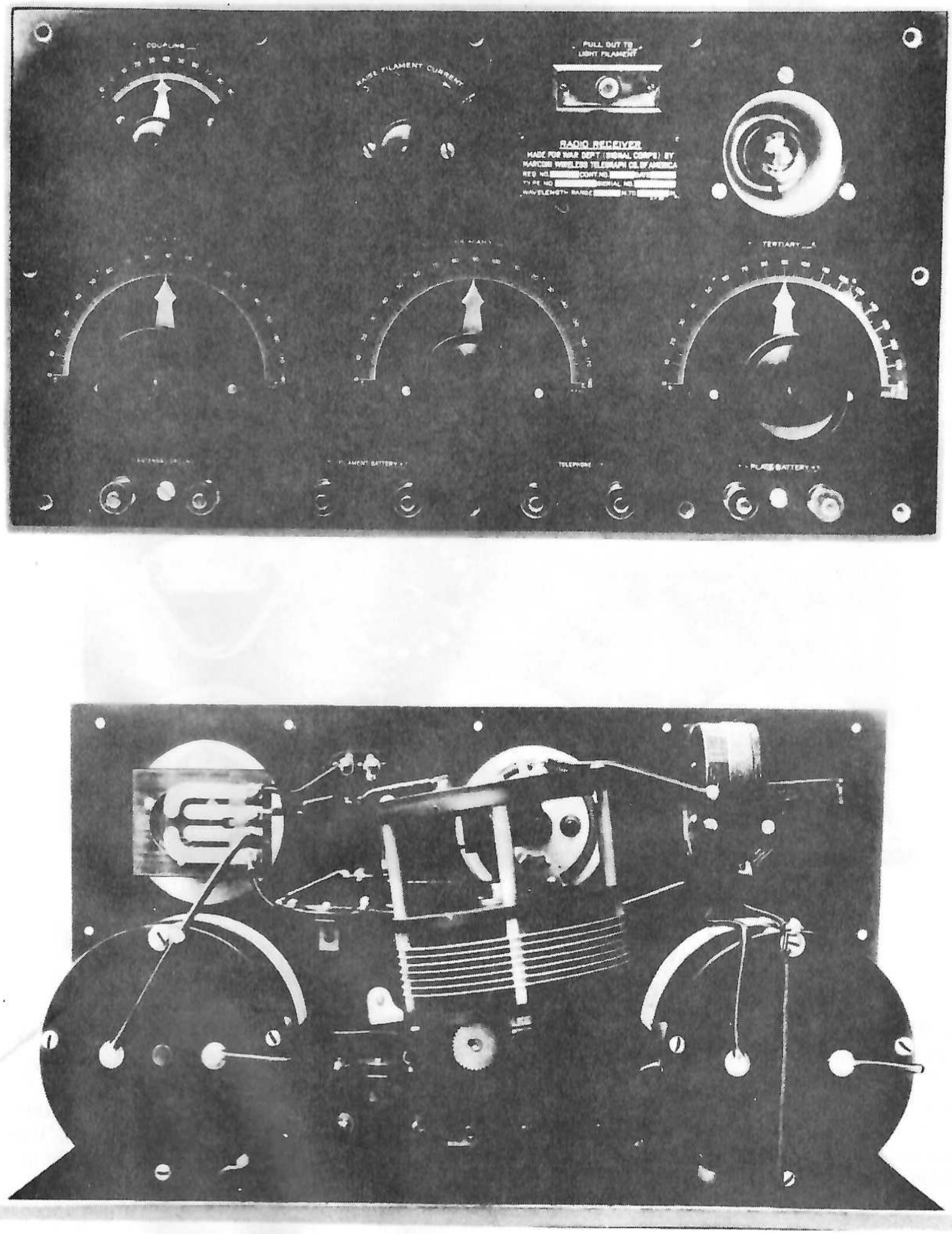


Figure 3. Intercept equipment World War I: for receiving waves 175 to 750 meters in length (front and rear views).

There is a certain irony in the fact that, at the very time when in the east the Russians were exposing themselves by clumsy use of radio, the Germans in the west were making the same mistakes. In the west it was the French who exploited the advantage at the Battle of the Marne. From the beginning of the campaign, which was designed to encircle and destroy the French armies in one decisive coup, the French were intercepting German radio messages and, through cryptanalysis and traffic analysis, learning more about order of battle and tactical plans than the Germans deemed possible. German radio discipline was lax and their procedures unimaginative. Errors in transmission of enciphered text were often corrected in the clear. Call signs of subordinate units were clearly linked to higher units by the same initial letter. Plain text messages were sometimes even signed in the clear. Of utmost importance were the so-called little things: The French frequently discovered and identified German radio stations because, when they changed call signs, German operators did not break the sequence of message numbers. One German divisional station could always be recognized because it put the sending time and word count at the end of the message instead of at the beginning. Another began each transmission with the stereotyped formula, "Can you hear all right?" In such cases it did no good to change the call sign.

With these assists, the French soon had a clear picture of the German operational structure in the west and could frustrate the master plan, committing the Germans to a long war of attrition in which the Allies had the advantage of greater material resources.

Direction Finding. Another form of passive ECM which began in World War I was the science of locating enemy radio transmitters by their radiated energy. Getting a radio "fix" is commonplace today, but in 1915 it was a novelty. The British first developed a system of direction finding early in the war for use against submarines. The Germans had direction-finding stations by the end of 1915. At about the same time the French set up their goniometric service. Coupled with the radio intercept stations, the direction-finder stations were first installed in fixed towers; mobile stations came later.

Because of the relatively few radio transmitters then employed in combat, direction-finding was nearly always of great intelligence value. The location of an enemy station coincided with the location of a unit staff, and the territorial distribution of stations revealed the organization of the enemy front. Troop movements could be detected by tracking the relocation of the radio stations.

On the other hand, direction-finding was by no means as simple as today. There were no maps showing local magnetic deviations, and these could be learned only by experience over given terrain.

Direction-finding operations achieved their greatest importance in the naval intercept service. The English in particular scored outstanding successes in determining the movement of German warships, particularly submarines. Many a German submarine sunk in those days could be credited to the British direction-finding service. Moreover, Zeppelin raids were observed constantly by the English with excellent results. Their task was rendered easier by the fact that the airships handled their radio traffic on a definite wavelength, worked with a fixed system of call signs, and flew at low speeds. As soon as a call sign was heard the British knew a raid was coming and they had merely to follow its course by taking bearings at short intervals.

The French were the first to develop goniometric equipment small enough to be installed in a vehicle. With this mobile direction finder the French scored notable successes, particularly in 1917 when the Germans were preparing to withdraw to the Hindenburg line. Well before the retreat, the Germans had radio transmitters operating along the new line. These were immediately detected by the French and their location determined. The imminence of the retreat, and the exact course of the new line, were at once apparent.

In 1918, portable direction-finding equipment was developed at Camp Alfred Vail (now Fort Monmouth) by the Signal Corps Radio Laboratories. The SCR-83 (fig. 4), the first of a series of portable, direction-finding radio receiving sets, was described as a flat pancake wound-loop antenna, approximately 6 feet square, supported on a framework and tripod, the whole being collapsible and arranged so that it would fold up into a portable package. The set box contained a vacuum tube detector, tuning condensers, switches, and telephone receivers. An airborne direction-finding radio receiving set, the SCR-84, having a wavelength range of 2,000 to 6,000 meters, was also developed at Camp Vail.

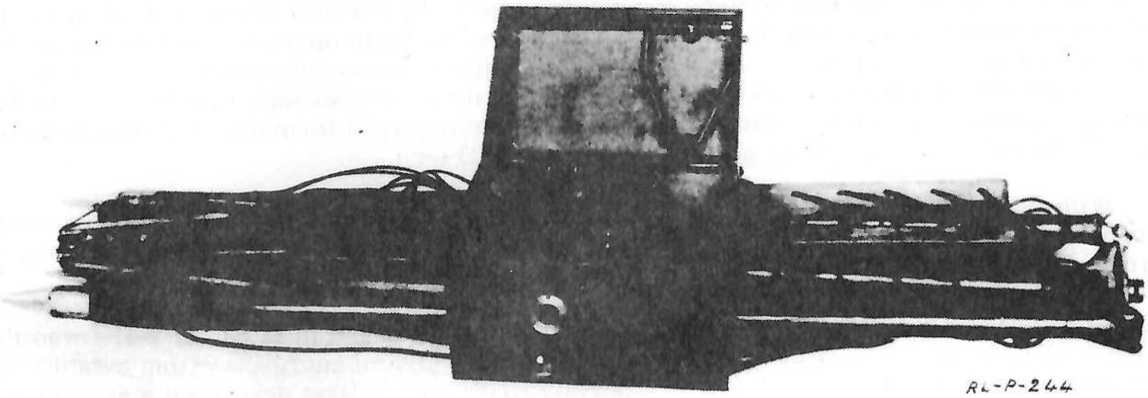


Figure 4. Portable direction-finder SCR-83, developed at Camp Vail during World War I.

In France, the Radio Section of the Radio Division, Signal Corps, AEF, originally consisting of 2 officers and 53 men but later increased to 12 officers and 402 men, intercepted enemy communications and located enemy radio transmitters and sent the resulting intelligence to the radio intelligence section of the General Staff for decrypting and interpretation. Stations operated by the Radio Section were of six kinds:

1. Intelligence intercept. These stations copied messages, usually in code, from German ground-radio stations.

2. Control. These stations monitored U. S. Army radio stations.

3. Goniometric. These stations secured bearings on enemy radio stations. They could measure direction within a couple of degrees. Two or more of these stations could obtain a fairly accurate map location of an enemy transmitter.

4. Airplane intercept. These stations intercepted enemy air-ground messages.

5. Airplane goniometric. These stations located enemy observation planes, and notified the Air Service, which sent out pursuit planes.

6. Listening stations. These stations copied telephone and earth telegraph messages. (See Wire Intercept, below.)

In all this work the Americans received valuable help from the more experienced French officers and men, who furnished equipment and trained the operators to use it. Frequently French and American operators worked side by side in the same station, for this work required the most expert radio operators and linguists.

Wire Intercept. If radio at this time was little better than an open book to the adversary, wire communications were not much more secure. During the trench warfare of 1914-15, when the trenches were only 50 yards apart and both sides were using single, ground-return lines, telephone conversations were easily intercepted by an extensive system of listening posts installed in front-line dugouts. Many methods were devised. The most dangerous was the direct tapping of the enemy's lines. As the front lines drifted farther and farther apart, divided by a no-man's land of barbed wire and mines, new methods had to be evolved, using the principle of electromagnetic induction. From each listening post insulated wire spread like tentacles throughout so-called "search grounds," which consisted of coppermesh mats or metallic rods buried as near as possible to the enemy's lines. By amplifying the stray ground currents and leaks thus intercepted, it was possible to read the messages. By means of a switchboard, search grounds could be selected to eavesdrop on any specific sector of the front.

The hazards of installing and repairing these lines can be easily imagined and the requirements for an operator were severe. Nevertheless, the listening-station service was a popular one. In February 1918, when the American First Division took its place on the southern flank of the St. Mihiel Salient and American personnel took over the listening service in this first American salient, operators were expected to be thoroughly familiar with the German language, including special military terms; to read buzzer messages in continental code through all kind of jamming and static; to copy telephone conversation in English without allowing dangerous talk to pass unheeded or so garbling properly coded messages that the innocent were censured; and to exercise judgment in giving information of immediate value to the local commander and in preparing the daily report of probable location of enemy stations and other pertinent data.

The fundamental piece of apparatus used in listening stations at this time, the SCR-72 amplifier (fig. 5), was developed by the Signal Corps and made in the United States. The system, which included a low-frequency filter to cut noise from power lines, motors and generators, was found superior to previous French and British systems.

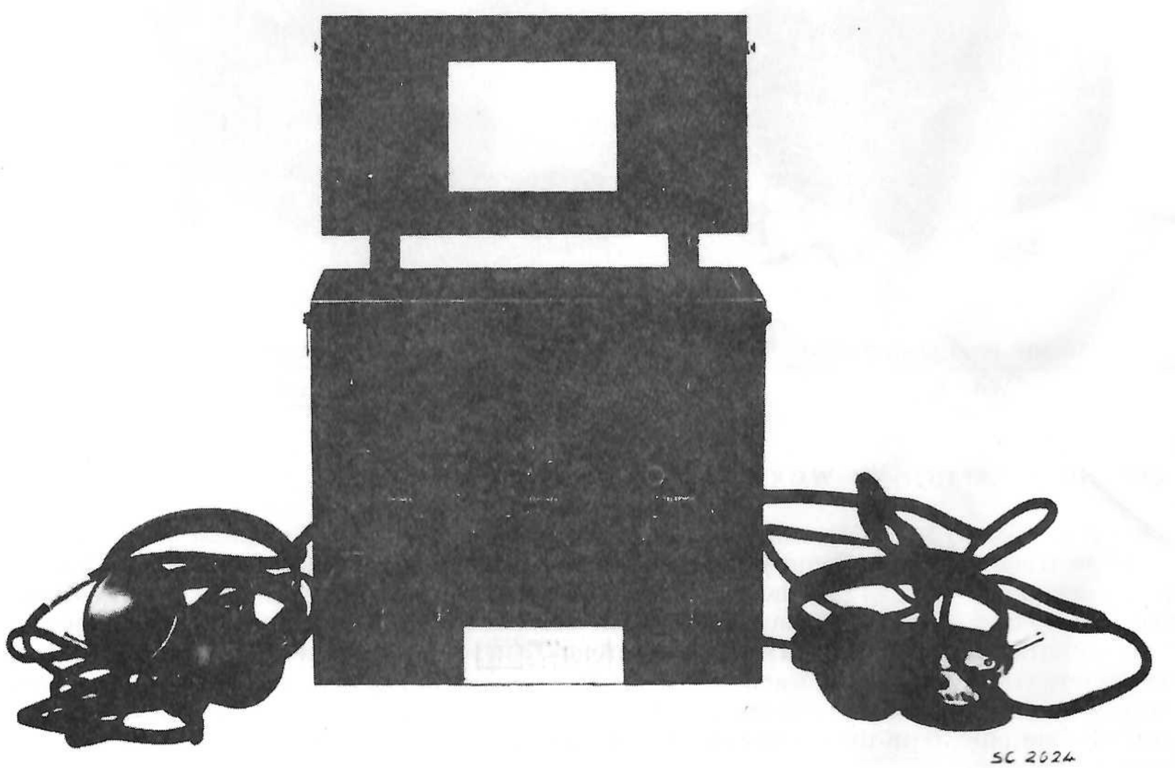


Figure 5. Low frequency amplifier SCR-72 used at listening posts, World War I.

## 5. ECCM IN WORLD WAR I

At the same time, to protect their own transmissions, the Allies were taking groping steps toward electronic counter-countermeasures. These took the form of improved circuitry. Wherever possible, two-wire telephone systems were built; but this was slow and sometimes impossible. Because of the continual damage to wire lines by shellfire, the service buzzer (fig. 6) was introduced in 1916. This was a combination of a telephone and high voltage telegraph set, which used a single conductor and ground return. When telephone transmission was impossible because of line damage, telegraphic signals could be transmitted and received in distant telephone receivers in the form of a high-pitched hum. On occasion, these signals were exchanged between buzzers after the line wire was severed, both the ends, however, being slightly grounded.

Buzzer signals could be intercepted, but not as easily as radio, and the messages could be encrypted. So the buzzer was somewhat more secure than the ordinary telephone. The British, however, had a non-inductive field telegraph instrument called the Fullerphone, which the French also adopted for forward telegraphy because of its increased security against interception. The Signal Corps redesigned the Fullerphone, overcoming certain undesirable features, substituting a tone for the buzzer, increasing the line current, and reducing the size and weight. The improved instrument, called the buzzerphone (fig. 7), was issued to American forces after our monitoring stations reported that it gave "absolute secrecy."

Figure 6. Buzzer type transmitter SCR-65, World War I.

Figure 7. Buzzerphone type EE-1A, modification of British Fullerphone.

## 6. ELECTRONIC DECEPTION IN WORLD WAR I

During World War I both adversaries experimented with electronic deception in its simpler forms -- false transmissions, dummy traffic, and similar ruses for misleading the enemy. Some were successful. Others had their humorous aspects. In the spring of 1916 the Russians attempted a radio deception which caused much amusement in the Austrian intercept service. To veil the withdrawal of two corps from the Austrian front, they had several radio stations carry on dummy traffic. They first announced the ruse in an encrypted radio message that was easily solved by the Austrians. They then betrayed themselves by adding, to each of the fake messages, the statement, in the same cipher, "Do not be disturbed, this is merely intended to mislead the enemy."

The Americans and the French were more successful in their deception efforts. During the Meuse-Argonne offensive, in November of 1918, a false army radio net was established on the Beaumont-Fresnes front and messages indicating an offensive on that front were transmitted in a cipher which the enemy would be sure to decipher from apparent carelessness in its use. Telephone lines were also established in such a manner that enemy stations could intercept messages designed to reinforce the deception. As a result, two enemy divisions were held in reserve at Metz because of fear of an attack east of the Meuse.

## 7. ACTIVE ECM IN WORLD WAR I

There are very few recorded incidents of communications jamming in World War I. Notable among these was the German jamming of the British shore-watch radio network on the shores of the Dardanelles to permit the escape of their warships Goegen and Breslau from the Black Sea into Turkish waters. There were several reasons why communications were not jammed more frequently. Many of these reasons are valid today. For example, the intelligence obtained by the passive countermeasures of search and intercept proved of great value in determining enemy plans and dispositions. Jamming these communications would not only have cut off the source of this intelligence but would also have warned the enemy that his transmissions were detected. Passive countermeasures are not detectable, so can betray nothing to the enemy. Active countermeasures can be readily detected by the enemy and often provide him with certain types of intelligence -- the extent of his adversary's technical knowledge, the imminence of hostile operations, and similar deductions. It was not until World War II that the gains overbalanced the risks and the high stakes forced bold measures.

## 8. PASSIVE ECM BETWEEN WARS

Meanwhile, during the period between wars, more than one nation profited from World War I experience in the field of radio interception. Diplomatic traffic continued to be monitored, and most nations intercepted radio traffic of foreign armies.

In 1928, Germany set up a military intercept service to gain military intelligence of her neighbors by observing all military maneuvers on the continent insofar as the range of German equipment permitted. The French, Austrians, Dutch, Belgians, and Italians were particularly vulnerable by geographic position, and information obtained by electronic surveillance gave the Germans vital insight into their troop organizations, tactics, weapons, air force employment, and air warning systems. The Russians, however, were less vulnerable to interception because of distance and improved communication procedures. They had profited from their wartime blunders. They now had the best radio procedure in all Europe and their cryptographic systems were in most cases incapable of solution.

The French intercept service was mainly directed toward military intercept, but the British, who could girdle the globe with intercept stations in their own possessions, observed all radio traffic of all nations, with complete coverage of diplomatic traffic. Poland had one of the best intercept organizations. Occasional cooperation, for specific purposes, was set up among certain nations, but was always hampered by mutual suspicion during these years of what was known as peace. Russia alone seems to have consistently operated alone. In <u>War Secrets of the Ether</u>, Wilhelm F. Flicke made the following comment:

> The Russian intercept service had the most obscure organization. That they attached great importance to it, however, was shown by the fact that in all communication formations they had large contingents for purely military intercept service. How the watching of foreign diplomatic and military radio traffic was carried out as a peace measure is shown only indirectly by the fact that they made use in their own radio traffic of all experience gained from the mistakes made by all other countries.

## 9. SCIENTIFIC DEVELOPMENTS

Shortly after World War I, American research scientists successfully used infrared to detect a light bomber at distances up to 22 miles. They also modulated infrared beams for voice communications at distances of more than six miles. But the development of radar turned military and scientific interest away from infrared for the time being.

The British are generally credited with the invention of radar, but application of this technique to detect aircraft and ships was also being studied secretly and independently in the United States, France, and Germany during the pre-war years. In the United States, as early as the twenties, the Signal Corps began experimenting with microwaves to produce echoes from nearby targets, but could not generate enough power at such short wavelengths to work out a practical detection system. The Navy, in the thirties, developed a method of detecting a moving aircraft by sending out continuous wave signals to a distant receiving station and observing the interference of the main ground wave with the wave reflected from the aircraft.

In 1925 two scientists of the Carnegie Institute used radio pulses to measure the height of the ionosphere, and the possibility of applying the pulse technique to the detection of aircraft and ships seems to have occurred simultaneously to scientists in the United States, England, France, and Germany.

Our Naval Research Laboratory made an important contribution by developing the duplexer, which enabled transmitting and receiving on the same radar antenna. The Signal Corps Laboratories developed an anti-aircraft detector for searchlight control and gunlaying that was successfully tested in 1938. An improved long-range model was designated a standard item of procurement in May 1940.

Meanwhile, in 1935, the British Air Ministry established a chain of five radar stations and increased it to 20 in 1937. These stations registered only distance to the target, but its location or azimuth could be determined by plotting its distance from three or more stations. With this chain, the first operational radar system anywhere in the world, a 24-hour radar watch was kept along the east and southeast coasts of England from Easter of 1939 until the end of World War II.

# *Section III. ELECTRONIC WARFARE IN WORLD WAR II*

## 10. THE WIZARD WAR

From the standpoint of electronic warfare, the development of radar and its manifold applications was one of the most significant aspects of World War II. Much has been written about the influence of this scientific breakthrough on the course and outcome of the war. Winston Churchill was one of the first to recognize its vital importance, for in 1940 he wrote of this highly classified subject:

> It is by devising new weapons, and above all by scientific leadership, that we shall best cope with the enemy's superior strength. If, for instance, the series of inventions now being developed to find and hit enemy aircraft, both from the air and from the ground, irrespective of visibility, realise what is hoped for them, not only the strategic but the munitions situation would be profoundly altered.... We must, therefore, regard the whole sphere of R.D.F [Radar], with its many refinements and measureless possibilities, as ranking in priority with the Air Force, of which it is in fact an essential part. The multiplication of high-class scientific personnel, as well as the training of those who will handle the new weapons and research work connected with them, should be the very spear-point of our thought and effort...

It would be impossible in this text to make more than brief mention of Allied radar. Some idea of the scope of the subject can be gained by a glance at statistics, for by the end of FY 1945 the United States alone had delivered to our services more than three billion dollars worth of radar equipment comprising some 150 systems.

What is not so generally known is that the Germans, too, had operational radar as early as 1939. They used it for early warning, for antiaircraft (AA) fire control, for ground control of fighter intercept (GCI), and in their night-fighters to detect approaching hostile aircraft. The Japanese also had radars, but in general they were not as sophisticated as German equipments.

The detection of these radars, first by the British and later by American ferret aircraft, and the desperate scientific war waged by the Allies to counter them, was the first full-scale exercise in electronic warfare. The account has all the elements of an adventure story -- daring photo reconnaissance, underground espionage, and commando raids. But unlike fiction or, for that matter, the usual military exercise, the outcome was to be a matter of life and death, not only for individuals but for nations as well.

Communications ECM became relatively unimportant. The great need now was for radar countermeasures to combat the enormous offensive and defensive advantages provided by this new scientific marvel. Overnight the character of warfare changed. Means and methods became obsolete. War was waged in laboratories and factories thousands of miles from the combat zone. Nations tried to out-think one another. It was not enough to develop a new and better radar. Scientists had to ask themselves, "If I were the enemy, how would I counter this? And if he does what I think he will do, how can I counter his countermeasures?"

In his war memoirs, Churchill wrote of the bombing of Britian:

> During the human struggle between the British and German Air Forces, between pilot and pilot, between anti-aircraft batteries and aircraft, between ruthless bombing and fortitude of the British people, another conflict was going on step by step, month by month. This was a secret war, whose battles were lost or won unknown to the public, and only with difficulty comprehended, even now, by those outside the small high scientific circles concerned. No such warfare had ever been waged by mortal man.... Unless British science had proved superior to German, and unless its strange sinister resources had been effectively brought to bear on the struggle for survival, we might well have been defeated, and, being defeated, destroyed.

Churchill coined another phrase. He called it "The Wizard War."

## 11. THE BATTLE OF THE BEAMS

The first phase of the Wizard War occurred in the air over England after the fall of France, when the German plan to reduce the British to submission by aerial bombardment was largely thwarted by a series of ingenious electronic deceptions. This operation, in all its many aspects, was called by Winston Churchill, "The Battle of the Beams."

The first German bombers to attack England early in 1940 were navigated by radio beacons beamed from a series of radio stations (200-900 kc) in northern France and Belgium. An aircraft equipped with a loop antenna could get on any of these beams and follow it directly over its target. The purpose of this and the other navigational systems the Germans tried was to allow blind flying in darkness or overcast, protecting their own aircraft and hampering the British defenses. Two countermeasures were possible. The aircraft receivers could be jammed, but this would alert the Germans and cause them to try something new. Instead, the British chose deception.

Lorenz and Meaconing. Among these German navigational systems was one known as Lorenz, which was countered by a system called Meacon (masking beacon) designed to bend the navigational beams. The British picked up the beamed signals and retransmitted them from a few miles away at a stronger level, using a directional antenna to intersect the original signal at a slight angle. German bomber pilots attempting to obtain bearings received signals from both the Lorenz transmitters and the Meacons. Since the British signals appeared to strengthen and the German signals to weaken as the aircraft proceeded toward its target, it was soon flying off-course along the bent beam. (See figure 8.)

Headache and Aspirin. Another navigational aid used by the Germans was a system of parallel beams, one transmitting dots, the other dashes, and carefully synchronized so that an aircraft flying between the two received a solid tone. Any deviation from course resulted in reception of either dots or dashes and could be quickly corrected.

The Germans called their system Knickebein (curtsey). The British, with characteristic wry humor called it Headache. As a result of good intelligence, the British were ready to counter Headache as soon as it appeared. They reinforced one of the beams by transmitting the same signal at much greater power. This, in effect, bent the beam, and the bombers were led off course. The bomber pilots, unaware of this deflection, dropped their bombs off-target. It is said that, after two months of wandering all over England bombing open fields (one night German bombers dropped 400 bombs and killed only two chickens), German aircrews began to suspect that the beams were not infallible, as Field Marshall Goering insisted they were. But it is also said they were afraid to tell him.

The British countermeasure, appropriately enough, was known as Aspirin.

Ruffian and Bromide. By the fall of 1940, the British needed another pain reliever. Bromide was devised to counter a new German bombing aid.

In those days the British Broadcasting Company (BBC) was not primarily an entertainment medium. But Radio Paris, broadcasting entertainment 24 hours a day, was generally listened to throughout the British Isles. British housewives went about their work to the sound of its music, and family groups listened in the evenings as we watch television today.

After the fall of France, the Germans capitalized on this British habit by interspersing propaganda on the Radio Paris broadcasts. The propaganda failed to have the desired effect on British morale, but was endured as are today's commercials rather than break the pleasant listening habit. So it was that the British housewives were credited with an important discovery.

More than one housewive observed that the volume of the Radio Paris broadcasts fluctuated in a rather peculiar way. If they had to turn down the volume in their radios, an air raid was sure to follow. Word of this phenomenon soon reached informed ears, and investigation disclosed that, coincidentally with these increases in volume before a raid, reception on radios outside the target area would fade.

There was only one possible conclusion: The Radio Paris transmitter was switching from an omnidirectional antenna just before a raid and beaming its transmission over the selected target area for use as a navigational aid. Another narrow intersecting beam which marked the bomb-release point was also detected. This was, in effect, a double-Lorenz system. The British called it Ruffian.

The British countermeasure Bromide consisted of retransmitting the Radio Paris broadcast on the same frequency, using an omnidirectional antenna to mask the directional beam (fig. 8) or, on occasion, a directional antenna to induce the bombers to drop their loads in the Channel.

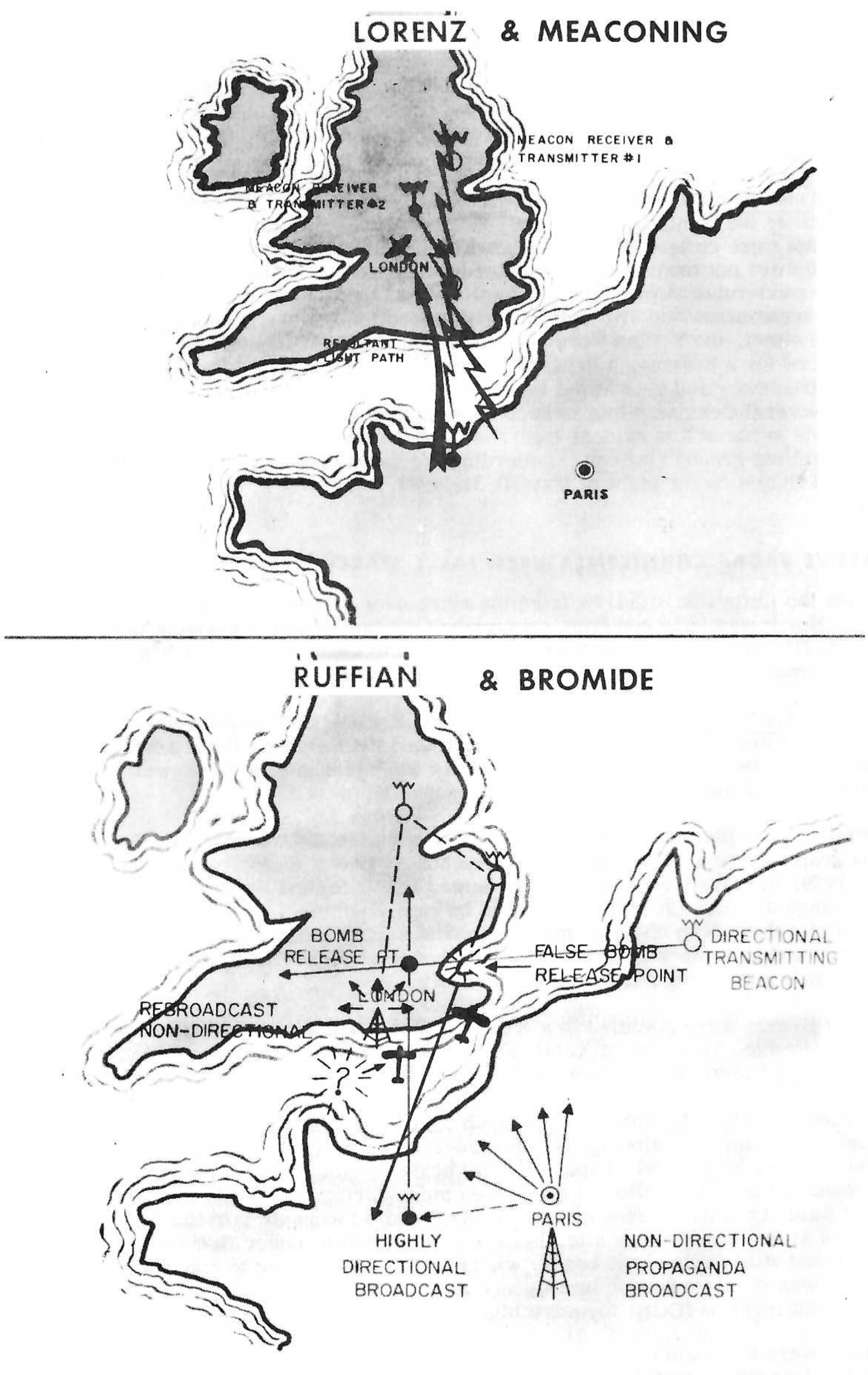


Figure 8. Electronic deception by the British during the Battle of Britain.

Starfish. A final effort was made to conquer the British from the air before the Luftwaffe was withdrawn to the Russian front. In one scheme, a German pathfinder air squadron, using all available navigation aids alternately to reach the target, dropped incendiaries to light the way for following squadrons. The British countered this by lighting decoy fires called Starfish in open areas to disperse the bomb load.

Benito and Domino. Another scheme, called Benito, used German agents with fm radios stationed along the bombing routes in France and England to talk the pilots in over their target. These agents were comparable to the forward observers for today's artillery fire control. The British were not monitoring frequency modulation, which was relatively uncommon then. But after considerable effort to obtain intelligence, the British solved the problem and intercepted the transmissions. Through imitative deception and the phenomenon known today as the fm capture effect, the British were able to create chaos and confusion. When a German navigator radioed for a bearing, a British operator who was a skilled linguist would cut in on the Luftwaffe frequency and give him a false bearing. This countermeasure was known as Domino. It caused several German pilots to become so disoriented that they were forced to land in England, and its success was evident from the bitter remarks heard passing between bombers and their controlling ground stations. (Recordings of these conversations are unprintable.) The bombing of Dublin on the night of May 30-31, 1941, may have been an inadvertent result of Domino.

## 12. PASSIVE RADAR COUNTERMEASURES: EARLY SEARCH OPERATIONS

When the Luftwaffe withdrew from the skies over Britain. the nature of the Wizard War changed. Now it was switched from countering German offensive systems to searching out and countering German defensive antiaircraft systems to clear the way for heavy RAF attacks against Germany.

Freya: for Warning. In November of 1940, British photo intelligence discovered an unidentified object near Cherbourg. But it was not until the following February that it was possible to obtain clear low altitude photographs. These were just in time to answer the question, "Do the Germans have radar?" at an Air Ministry meeting next day.

Details of the pictures provided data on frequencies and waveforms. They disclosed an antenna shaped "like a bedspring sitting on a box." One of the oldest German radars, dating back to 1939, this early warning set was named Freya for the Norse goddess of love and beauty. It had a range of about 120 miles and could be easily jammed. Its job was to spot remote aircraft and plot them in to about 25 miles. It could supply range with an accuracy of plus or minus 100 meters and azimuth with an accuracy of about one degree. Accurate height-finding was left to the Freya's gun-laying partner, the Wurzburg.

Early Freyas were installed in a fixed chain of early warning stations. A later 5-ton model was transportable. Two other coastal radars, Hoarding and Chimney, were believed to have a range half again as great as Freya, and to give height as well as range and azimuth of aircraft.

Wurzburg: for GCI. Subsequent search operations were dramatic. A daring low-level photo reconnaissance mission against the radar-defended continent yielded shots of something that looked like a large bowl-shaped electric heater -- the first paraboloid, or dish, antenna. This reconnaissance was followed by an even more daring commando raid, famous as the Bruneval Raid. On a dark, snowy night, an RAF radio mechanic landed with a detachment of paratroops at the enemy radar site. In barely ten minutes, under fire, he dismantled the radar and evacuated vital parts to the beach, where a boat was waiting to take the party back to England. This was the first British intelligence of the Wurzburg, used by the Germans for ground-control of interception (GCI), for searchlight and AA fire control, and for height finding.

There were two main types. The Small Wurzburg had a nine-foot dish antenna which operated by hand-crank. A mobile decimeter radar, trailer-mounted, it weighed about two tons, had a range of 1-24 miles, and operated on a frequency of about 500-600 megacycles. Inferior to comparable Allied equipment, it required two operators and had no plan position indicator (PPI) to facilitate plotting. These radars were first used in 1940, and by D-Day were much improved. In 1944 the Allies estimated there were about 2,000 Small Wurzburgs in operation in Nazi territory, with 100 more being produced each month.

The Giant Wurzburg followed the small one by nearly two years. A fixed installation, it weighed 12 tons, and its dish was 24 feet across. Its range was double that of the Small Wurzburg -- about 45 miles -- its beam was narrower, and its chief role was GCI. There were an estimated 1,000 of them in Europe at D-Day.

Benito. This equipment, familiar to the British from the Battle of the Beams, was radio direction-finding equipment rather than radar. Not easily jammed, it gave slant range and bearing of aircraft. It was used for ground control of fighters.

Lichtenstein: for AI. At the start of the war, the Germans had no aircraft interception (AI) radar, but instead a crude infrared device called Spanner. In 1941, to defend against British bombing attacks, they fitted another type of radar, the Lichtenstein, into their night fighter aircraft. A clumsy affair, it weighed 110 pounds, not counting antenna and cabling. It had a range of about one and a quarter miles at high altitude, but lost targets in ground clutter at low altitudes.

Since it was essential to know about this radar in order to jam it, the British sent over a decoy aircraft bearing a special operator at a listening receiver. The aircraft was attacked eleven times by an enemy night fighter radiating the Lichtenstein emissions. The operator, though suffering severe head wounds, completed his mission and was parachuted over England with his vital log of observations before the wounded crew set their aircraft down in the English Channel because it was too badly damaged to land. All were rescued, and the British knowledge of German radar defenses was complete.

Tactical Employment. The Germans arranged their ground control system in "boxes" within sectors within the continental radar net. Each sector had a central control room. Figure 9 depicts a hypothetical sector, consisting of three adjacent GCI stations, much simplified and condensed, with only key equipment shown. Sector headquarters (the chateau in the middle box) received warnings from coastal Freyas and directed all action. The middle formation is clearly in trouble. Flying straight in through Freya's range, it has put itself on Wurzburg's beam with no evasive action. The formation at the left is jamming to confuse a Wurzburg-directed fighter. The formation at the right is snaking along box boundaries to gain time while the boxes decide who should take the target. These boxes measured at least 20 miles in frontage, 60 miles in depth.

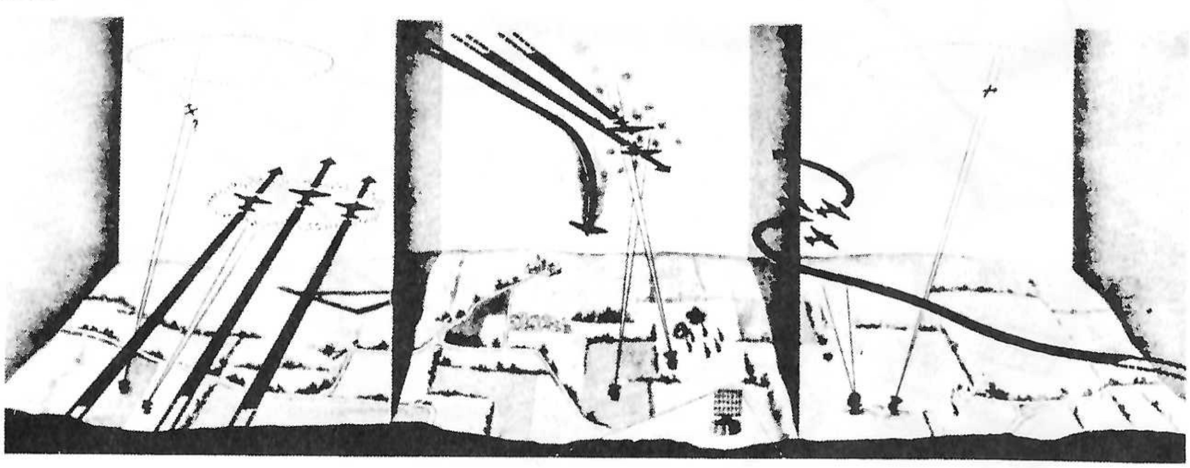

Figure 9. German tactical employment of radar, World War II.

## 13. ACTIVE ELECTRONIC COUNTERMEASURES: NONCOM-ECM

Early Radar Jamming. The United States observed with keen interest the battle between offensive electronic systems and the countermeasures techniques employed to reduce their effectiveness. It was apparent that future operations, especially in the air, would depend increasingly on electronic warning and control systems, and that these systems were susceptible to countermeasures action. Accordingly, soon after we entered the war, a small group of American scientists was sent to England to work in the RAF radiation countermeasures program. With this embryonic organization a laboratory was established at Great Malvern, England, for work on countermeasures design. Here was produced, in early 1943, the first US designed jammer, the AN/APT-1.

The British and Germans had already begun jamming one another's radars. Facing the British chain of early-warning radars across the Channel was the German coastal chain whose radar-controlled guns and searchlights seriously hampered movement of British shipping. But British bomber crews returning from missions on the continent made a discovery. When they switched on their IFF transmitters, the enemy's searchlights sometimes went out or turned away. Examination of captured German radar equipment disclosed that they could be accidentally jammed by the IFF sets. The British hastily fitted these sets with devices that made the jamming no accident. They also constructed ground jammers, which effectively countered the German early warning radars.

On the night of 11 February 1942, however, the Germans turned the tables by jamming the British radars and moving through the Channel and into the North Sea three warships -- the Scharnhorst, Gneisenau, and Prinz Eugen -- that the British throught were safely bottled up in the habor at Brest. During this classic ECM operation (fig. 10), the German jamming was so skillful -- slight at first but gradually intensified -- that British radar experts manning coastal

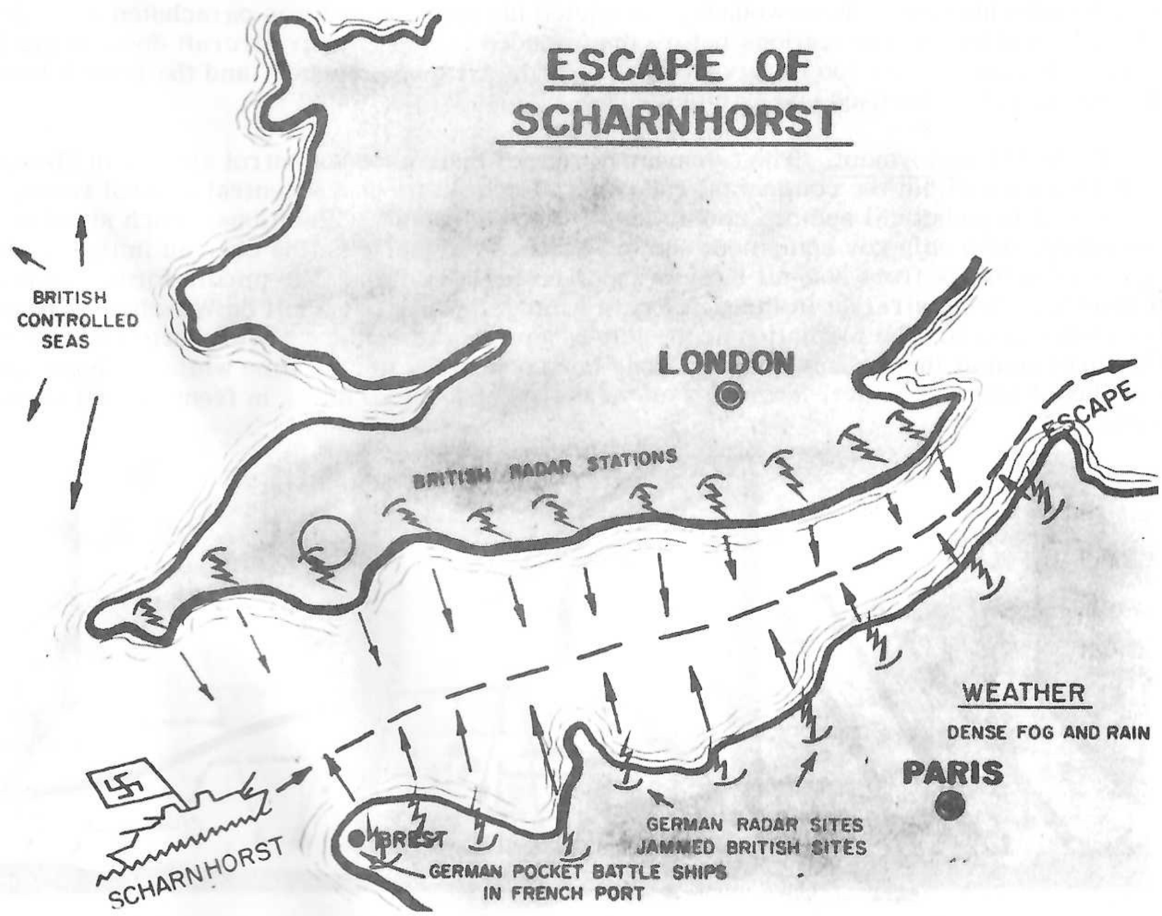


Figure 10. German jamming of British coastal radars, World War II.

stations were not aware of what was happening until too late. Every British radar was jammed but one -- and the British did not believe that one. Even though the life of the Scharnhorst was prolonged, the British learned a profitable lesson. The effectiveness of radar jamming was proved, and the Germans had betrayed their capabilities.

This last factor is always a consideration in the decision to jam. After its initial use, the effectiveness of a countermeasure depreciates. Once used, it is an open target for counter-countermeasures or for adoption by the enemy against our own defenses. The classic illustration of this dilemma was the controversy over whether or not to use the electronic countermeasure, more properly described as a confusion device, that was known to the British as Window and to us as Chaff.

Window. Window had been suggested as a radar countermeasure as early as 1937, but the British had been afraid to introduce it because it was such a simple device that the Germans could adopt and turn it against its originators. After the war, it developed that the Germans had known about Window all the time but had refrained from its use for the same reason. Window was simply aluminum strips like Christmas-tree tinsel (fig. 11). When scattered from an aircraft, it filled defending radar scopes with a galaxy of blips from which it was impossible to distinguish echoes of the actual bombers. Known technically as tuned dipoles, these metallic strips were cut to a length that would cause them to resonate at the frequency of the radio waves emitted by the radar.

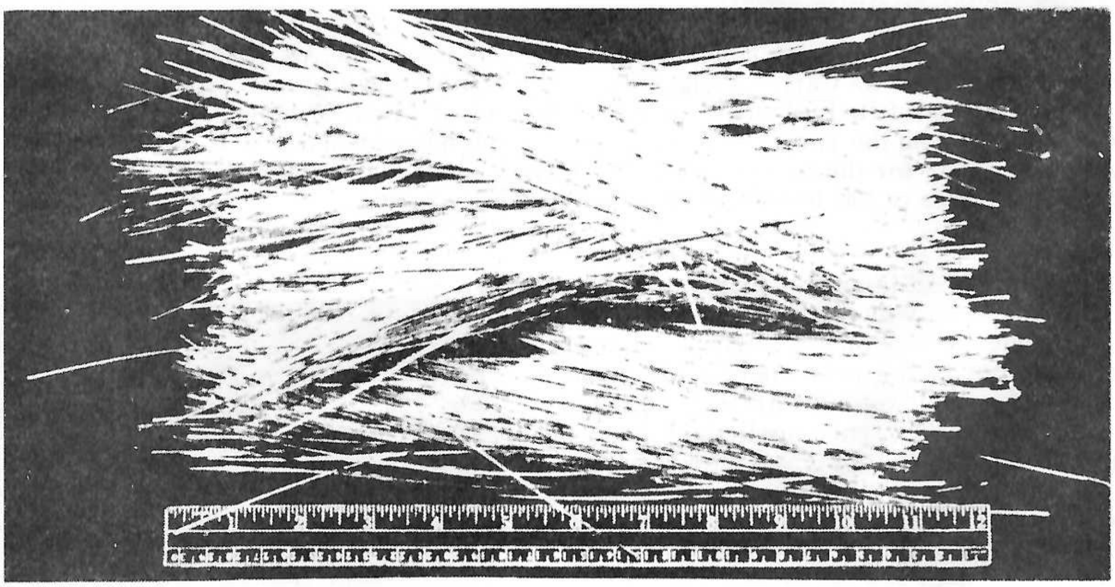

Figure 11. Window: confusion device, World War II.

The German radars operated at frequencies of from 100 to 600 megacycles, with most of them bunched between 550 and 570 megacycles. The narrow bandwidth made them highly vulnerable to jamming. And, by an odd coincidence, the German frequencies were those which required the smallest weight of Window to simulate a four-motored bomber on a radar screen.

After many misgivings and prayerful consideration of relative air superiority, the Allies finally decided to use Window to screen their massive raids on Hamburg in July 1943. The resulting air strikes by both British and American bombers virtually obliterated Hamburg. The German operators, when multiple blips appeared on their radar screens, reported in consternation that the British planes were reproducing. The first night alone, 791 bombers each dropped one bundle of 2,000 foil strips every minute along a planned route, creating enough echoes on radar scopes to simulate an estimated 12,500 aircraft. Only 12 bombers were lost that night, and those only by chance interception or blind flak hits. The bombers, virtually free from air or ground defense because the control stations could not locate them, dropped a total of more than 7,000 tons of high explosive and incendiary bombs in five days and nights.

The results have been compared to the atom-bombing of Japan. An official German report characterized the damage as "beyond all human imagination," and described the burning city as "a fire typhoon such as was never before witnessed, against which every human resistance was quite useless."

The Germans used Window six weeks later with devastating effect in a raid on an Allied base, and for the rest of the war it proved a potent offensive tool on both sides.

Other Confusion Devices. British Window was soon being augmented by American Chaff, cut by machines developed for the Signal Corps, at the rate of 200 tons a week. Better launching chutes and automatic dispensers were developed, tactical employment of Chaff as a confusion device and its use in deception were studied. (See paragraph 16.) A new type of confusion device, called Rope, was tested and became operational in 1944, particularly in the Pacific Theater. A logical teammate to Chaff, its 400 feet of aluminum foil effectively jammed low-frequency radars over a broad band. It could be launched attached to a 1-inch parachute for use against vertically-polarized radars, or to a 3-inch card for horizontal polarization. Before the war ended the September 1945 issue of Radar reported on the possibility that the Japanese were experimenting with metallized clouds or powder instead of the conventional Window to clutter up Allied radars.

Carpet. Meanwhile, American scientists had developed the AN/APT-2, an airborne electronic jammer known as Carpet I (fig. 12), which bombarded a ground radar with signals tuned to its frequency and filled its entire scope with spurious blips. Window affected only the area of the scope showing the range at which the confusion device was located. Moreover, it could provide cover only for the followers in a formation, not for the lead aircraft. Carpet was designed to take care of the lead aircraft as well as the whole formation.

The British had jammed German radars in North Africa simply by transmitting the roar of their airplane engines on the German radar frequency. Carpet used a refinement of this type of interference -- a powerful, carefully directed and controlled interference spelled out in terms of sine waves, fm or am signals, modulation, and the like. Each of the early Carpet jammers could radiate 6 watts of noise-modulated cw in a 7-megacycle band, and the center frequency could be tuned over a wide range. Two hundred of this model, produced by the U. S. Army Signal Corps, were tested in England in the summer of 1943 and proved effective, especially when used with Window. It became operational in October of that year, and by the middle of 1944 an improved model, the AN/APQ-9, called Carpet III (fig. 13) was available in limited numbers. This later model had about four times the power and jamming capability of Carpet I.

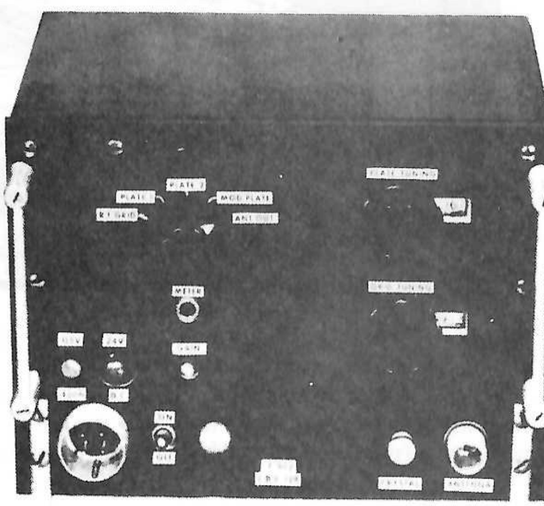

Figure 12. Carpet I.

Other Electronic Jammers. But American ingenuity had only begun to function. In the year before D-Day the Signal Corps developed and was crash-producing for the British as well as our own Air Corps several new electronic jammers called variously Mandrel (AN/APT-3),

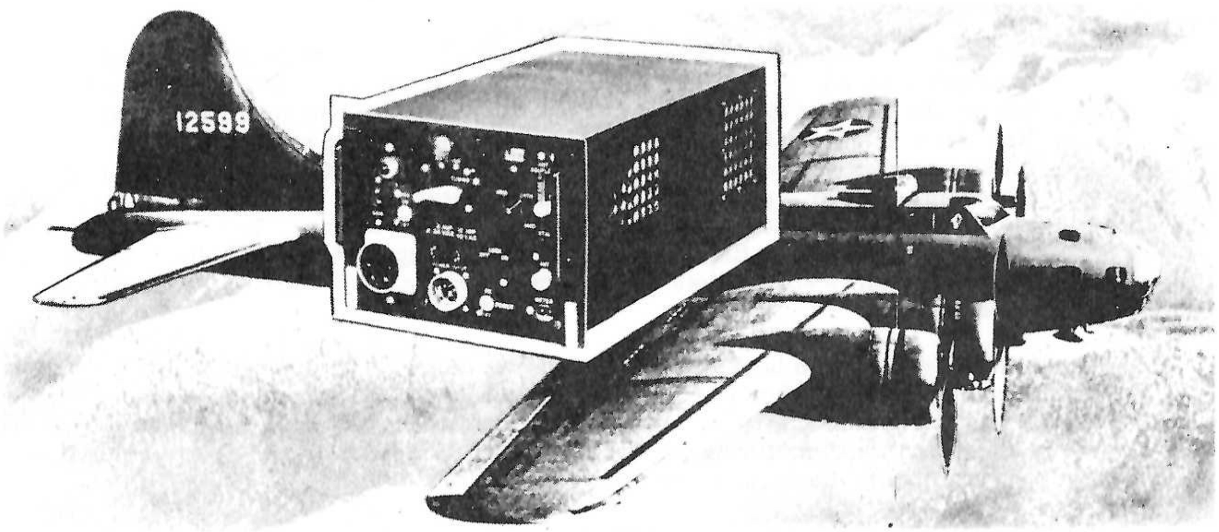


Figure 13. Carpet III.

Rug, Dina, Jackal, Airborne Cigar, and Tuba. All but the last were of relatively low power, under 400 watts, and could only be used effectively by aircraft flying close over the enemy's receivers. But Tuba, which employed the new resnatron tube developed in the United States, was a monster transmitter, comparable to the most powerful American broadcasting stations, but having a frequency five times as high. Developed chiefly by the NDRC with Signal Corps support, it delivered from 20 to 30 kilowatts in actual field operations, with a gain from the huge parabolic antenna of 600 to 1. It could jam airborne radars from ground locations at considerable distances, but by the time it was set up in England, at the time of the V-bomb attacks, the need for it was virtually gone.

Many jammers were scratchbuilt by American and British scientists to meet a particular need at a particular time, and as D-Day approached the program accelerated enormously, with the Signal Corps alone working on as many as 64 ECM projects, principally active or radiating jammers. From June 1943 to June 1944 the quantities of ECM airborne sets delivered to the Army Air Corps increased from about a hundred to the tens of thousands. The Allies were taking charge in the Wizard War.

## 14. ACTIVE ELECTRONIC COUNTERMEASURES: COM-ECM

After Hamburg, the German defense against the British massed bombing formations was to plot the height, direction, and whereabouts of the main bomber stream and to broadcast this information to fighter planes in the air. As soon as the actual or probably target of attack was determined, the German ground controller dispatched the fighters to its defense. To neutralize this tactic, the British equipped bombers with a new light-weight communications jammer, code-named Airborne Cigar, consisting of a receiver that automatically searched out the German frequency and a jamming transmitter that blotted out the voice channel at the flick of a switch. This was so effective that the Germans resorted to broadcasting over a high-powered station. Since the German controller's commentary was not in code, German-speaking British operators could simulate these broadcasts at ground stations tuned to the same frequency, and soon the controllers were being harrassed by ghost voices. The British operators not only spoke idiomatic German but were chosen for their ability to mimic, and when the Germans switched suddenly to a woman broadcaster, the British were ready with a German-speaking Englishwoman. Allan A. Michie, in "The Greatest Hoax of the War," (Reader's Digest, October 1946) described the resulting confusion:

This technique, called Operation "Corona," was first used on the night of October 22-23, 1943, when RAF bombers made a heavy attack on Kassel. During the raid the Germans caught on that something had gone wrong and RAF radio monitors heard the German controller telling his night fighter pilots to "beware of another voice," warning them "not to be led astray by the enemy." After a particularly violent outburst by the German controller, the "ghost" voice said: "The Englishman is now swearing." The German shouted, "It is not the Englishman who is swearing, but me!" By the end of the raid the German pilots were so confused that they were yelling abuse at each other.

Another favorite British hoax was to intersperse selected recordings of Hitler's speeches on these broadcasts. Sir Arthur Harris, Marshall of the RAF, in his book, Bomber Offensive, wrote: "It was very satisfactory to imagine the irritation of the enemy crews as they flew aimlessly about in darkness, trying to pick up the instructions they knew were being broadcast to them but getting only the screams of their Feuhrer."

## 15. RADAR COUNTER-COUNTERMEASURES: ANTIJAMMING

Axis. Antijamming in World War II was a grave problem for the Axis nations and one they never completely solved. This failure weighed heavily in the ultimate outcome of the war. Put on the defensive, they stayed there, and were never able to take charge. An editorial in the September 1945 issue of Radar put it this way:

> Allied RCM [radar countermeasures] not only jammed enemy radar but jammed their scientists. In an effort to salvage their huge investment in ground radar equipment which our countermeasures were rendering ineffective, the Germans diverted an extraordinary amount of their best scientific effort to anti-jamming research and development. This diversion of effort, resulting from our RCM program, seriously delayed the development and introduction of more advanced radar equipment.

The Germans had standardized on relatively few models of radar equipment, and these did not operate in the ultrahigh frequency range. The Allies took advantage of this lapse in devising countermeasures. But the Germans, instead of shifting to microwave radar, which is much harder to jam, applied anti-jamming techniques to their low-frequency systems. They spread operating frequencies ever more widely, mounted low-frequency radar at Wurzburg sites to take over when the higher frequency radar was jammed, and devised antijamming circuits. An antijamming panel found on a captured Small Wurzburg combined a propeller modulation device, a moving-target discriminator, and a wavefront discriminator. One of several modifications to help operators distinguish true from false echoes used the Doppler effect. All such devices reduced the effective range. Frequently the Germans were forced to fall back on visual range finders, when conditions permitted, and on relatively inefficient barrage fire against blind attacks.

Carpet was particularly effective against the German radars, especially when used with Window. For the German anti-jamming techniques proved unable to cope with both. If they shifted frequencies to avoid Carpet they were vulnerable to Window; and their anti-Window attachments, designed to distinguish between moving and stationary targets, made their radars more vulnerable to Carpet. Results of early Carpet operations, shown in figure 14, seemed to indicate that the Germans had not yet come up with an effective counter-countermeasure. But as an observer pointed out in the spring of 1944 --

> All of which, if true at all, may be true today and not true tomorrow. The only way to keep a countermeasure out in front of the possible counter-countermeasure is to keep improving the countermeasure.

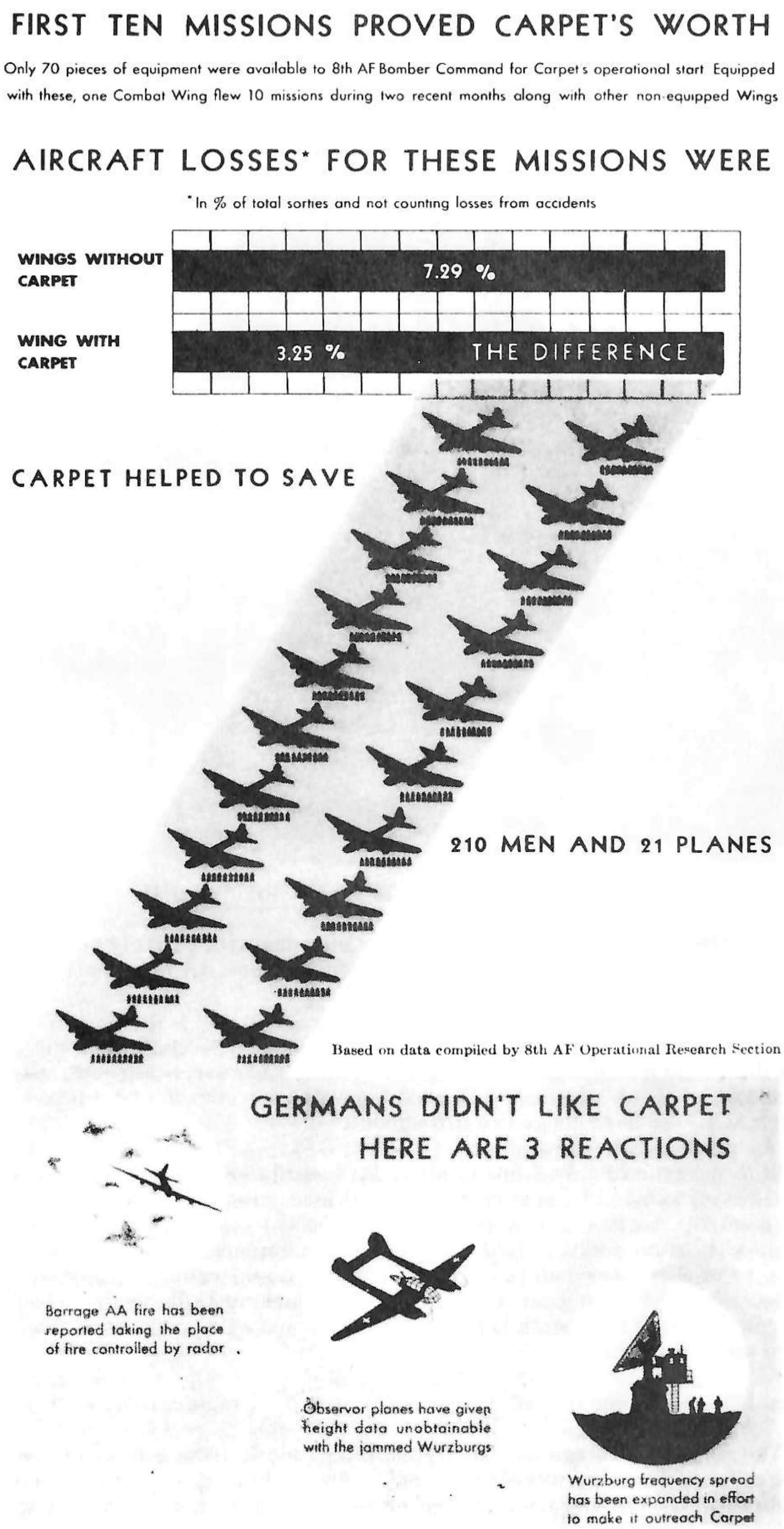


Figure 14. Results of early Carpet missions, World War II.

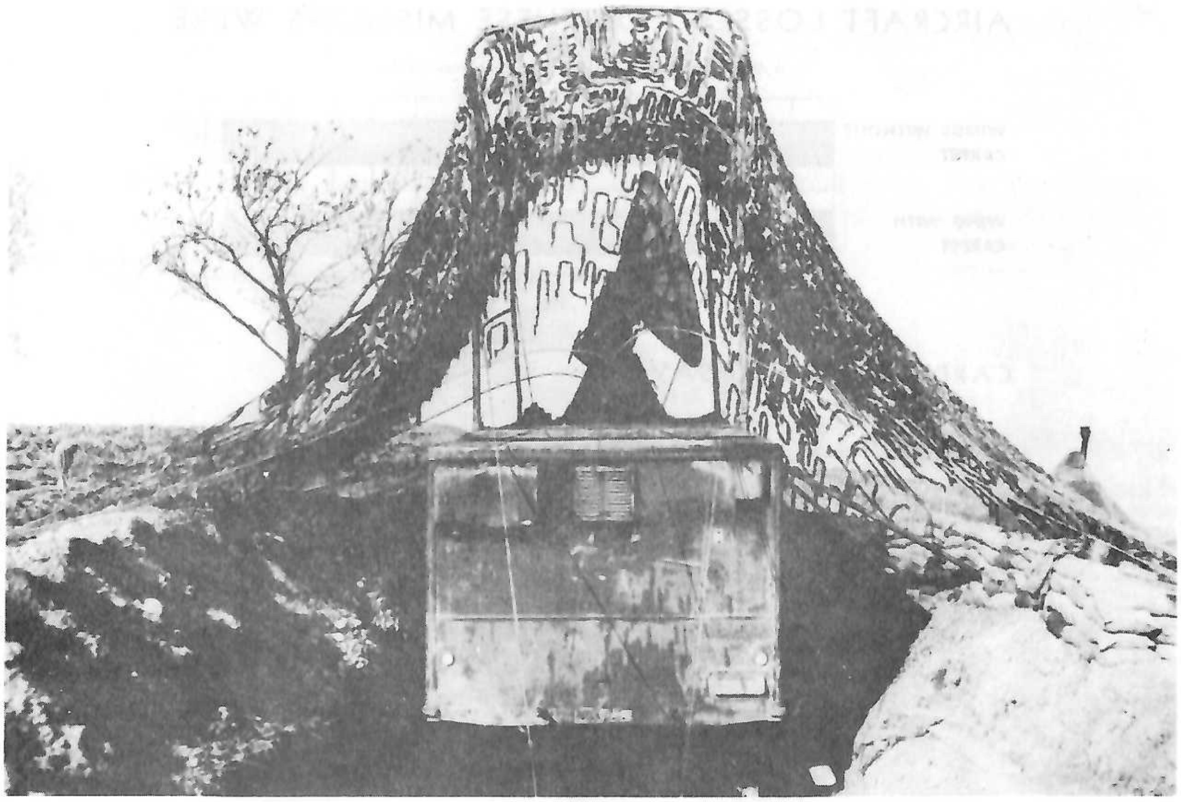

Figure 15. SCR-584 in Italy, World War II.

Allied. The Allies, however, achieved better success with entirely new equipment designed to counter jamming. An example of the influence of one AA fire control radar on an important engagement may well prove instructive here.

The radar was the SCR-584, prototype of the present AN/MPQ-16, and the engagement was the defense of the Anzio beachhead. The SCR-584 was microwave equipment. Of the other two fire control radars involved, the SCR-545 used longwave for search and microwave for fire control, and the SCR-268 used longwave throughout.

In the tight situation on the beachhead all radars were highly vulnerable to jamming. The 268's were effectively blinded by enemy Window and land jammers. Then 16 new mobile, microwave, AA fire control radars (12 SCR-584's, 4 SCR-545's) reached the hard-pressed beachhead and were dug in at the hearts of 90-mm gun emplacements. None of the crews had seen previous action, and only a few had previously operated comparable equipment. Nevertheless they helped knock down 46 enemy aircraft, discouraged enemy raids in the congested 100-square mile area, stopped formation bombing entirely, and substantially neutralized the effects of concentrated enemy jamming.

The September 1945 issue of Radar showed the results graphically (fig. 16) and reported:

> The best defense against enemy jamming, aside from all-important savvy of the operators, is equipment that isn't vulnerable to it. Against the countermeasures which the Jerries piled on the Anzio radars, none of the equipment operated without disturbance. But the microwave radar did operate, and that was the measure of the fire control success at Anzio.

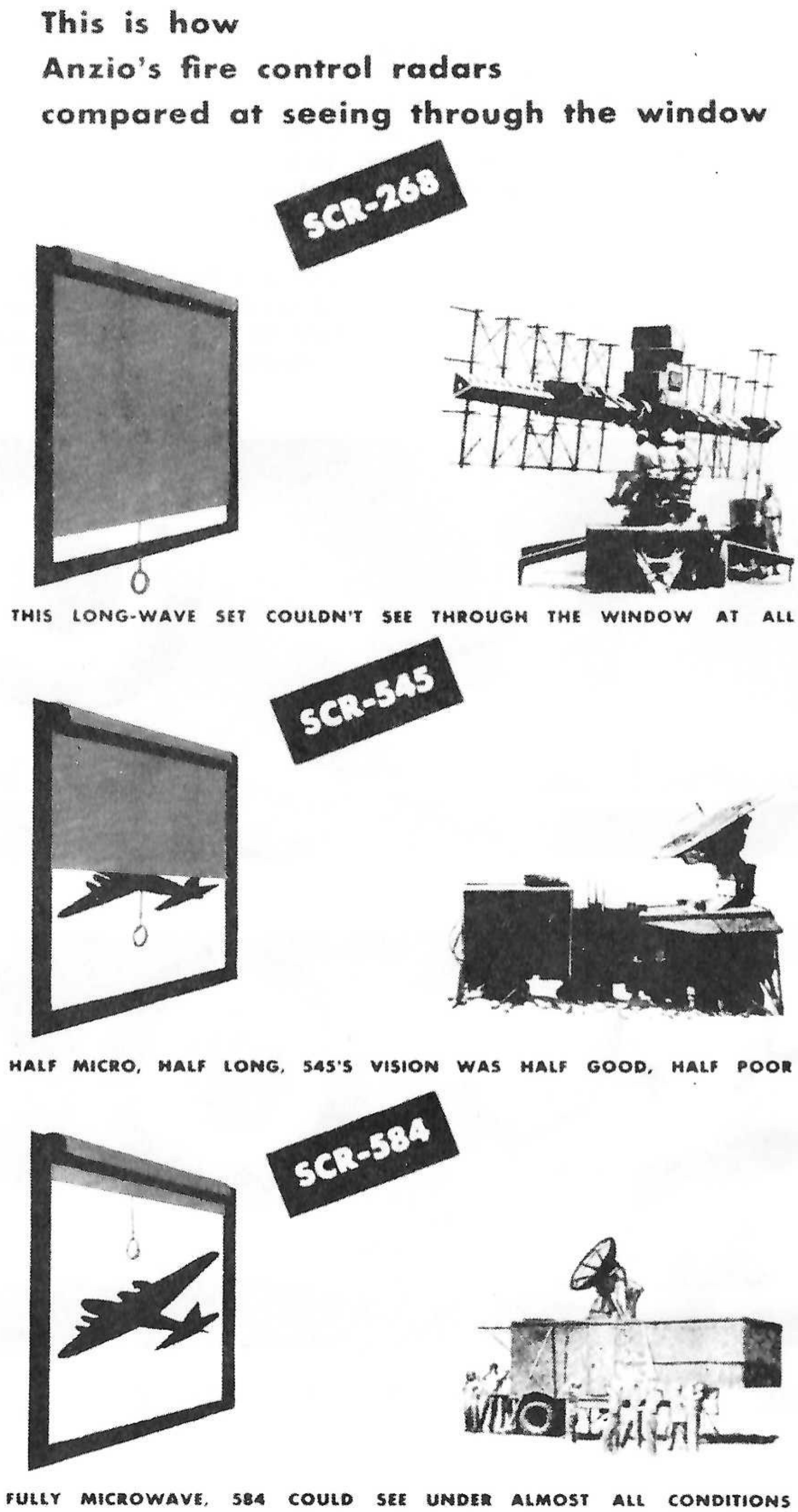


Figure 16. Anti-jamming operation in World War II.