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THE RADIO PROXIMITY FUZE

by

DR. L. GRANT HECTOR, Ph.D.*

THE NEED FOR A PROXIMITY FUZE

Before the Second World War, anti-aircraft fire was notoriously ineffective due not only to the lack of effectiveness of tracking and aiming systems but, of at least equal importance, to the difficulty of attaining the necessary accuracy in the setting of time fuzes to assure explosion of the shell in the proper position with respect to the plane at which it was directed.

The first of these difficulties was minimized by applying radar and electronic tracking equipment to the automatic control of gun aiming.

The second difficulty pointed to the need for a fuze that would be triggered, quite automatically, by the object to be hit. Such a fuze was called an "influence" fuze and also a "proximity" fuze. The need for such a fuze was given great emphasis in the early part of the war by the sinking of large battleships by land-based planes.

That the attack on these two aspects of the problem of improvement of anti-aircraft fire was successful is indicated by the fact that before the development of the improved aiming devices, fire, in the order of tens of thousands of rounds, on the average, was required to bring down a single enemy plane. The use of the new aiming and tracking equipment reduced the number of rounds per plane brought down to the order of thousands. The addition of the radio proximity fuze to the anti-aircraft protection further reduced the necessary fire to the order of hundreds of rounds per plane destroyed.

TYPES OF PROXIMITY FUZES

Many types of influence fuzes have been proposed. The best known is probably the magnetic type used in mines. For explosive devices other than mines, three general classes of proximity fuzes have received major attention. These are the microphonic, photoelectric and radio types. Except in certain mine applications the microphonic type did not prove successful. The British as well as the Americans gave early attention to the photoelectric and radio types for use in bombs, rockets and shells. The photoelectric type was made to operate successfully in bombs and rockets. On the other hand, the radio type was successful in all three fields of application.

RUGGED FUZES

This presentation is concerned primarily with the radio type fuze as used in shells. The important distinction to be noted between a fuze used in a shell - that is, a high speed projectile - and a fuze used in bombs and rockets lies in the fact that in the shell the fuze and all its component elements are subjected to a vastly higher order of magnitude of forces than is a fuze used in a bomb or rocket.

In general, shells are fired at high velocity from rifled cannon. For instance, in 5" naval guns the forward acceleration may be of the order of 15,000 times the normal gravitational acceleration. Furthermore, for objects at one inch from the center of rotation, the centrifugal forces due to spin may be of the same order of magnitude in some guns as the forward forces. In addition, forces occur resulting from vibratory motions of the projectile, particularly when fired from worn guns, and additional, similar, forces occur in flight because a rapidly rotating projectile tends to yaw in its flight.

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*Director of Research and Engineering, Sonotone Corporation, Elmsford, N.Y., Dr. Hector, on leave from the University of Buffalo as Professor of Physics, was in charge of the Electronics Development Section of Section T, Office of Scientific Research and Development, during the development and early production of the minute and especially rugged electron tubes which made possible the Navy Department's successful VT Fuze.

A paper delivered at the October, 1945 meeting of The Radio Club of America, New York City.

None of these effects are present to a comparable degree in the cases of bombs and rockets. While electronic problems to be solved in meeting the needs of these two general types of service present similar difficulties, the mechanical requirements to be satisfied in the case of the shell sets the shell-fuze apart as a separate problem, and will justify the characterization of the shell-fuze as a whole, as well as all of its components, as distinctly "rugged".

In the division of responsibility in the early days of the war, the Navy took on the sponsorship of proximity fuzes for shells, and the Army guided the work on proximity fuzes for bombs and rockets. The shell-fuze reached high scale production first, and was at first used exclusively for its original purpose, namely, the protection of the United States Fleet against aircraft attack. The Navy also assumed responsibility for supplying this fuze to the British Navy, the American Army and the British Army in that order of priority. Later in the war, fuzes for use in howitzers were also supplied by the Navy for use by the Army.

When radio proximity fuzes of the rugged type were developed under Navy sponsorship, they were given the name "VT Fuzes" by Captain Shumaker, Head of the Ordnance Bureau of the Navy. That designation - the contraction of "variable time" had been used previously by the British in their early work on proximity fuzes. When the same fuzes were used by the United States Army they were designated by the code name "POZIT".

THE USE OF THE RUGGED VT FUZE

The VT Fuze was in mass production by the fall of 1942 and was first used in battle action in the Pacific Theater in January of 1943. Since that date no battleships and no light cruisers have been lost by aircraft attack, and only one heavy cruiser and one aircraft carrier was so lost. This remarkable defense record is, of course, due to the combined anti-aircraft techniques available to the Navy, and it stands in strong contrast to the sinkings of large naval units, both of the American and British Fleets, in the earlier days of the war.

The Navy VT fuze was first used only over water in order that the enemy might have no opportunity to recover duds for study. However, its use over land by the Army was contemplated from the start.

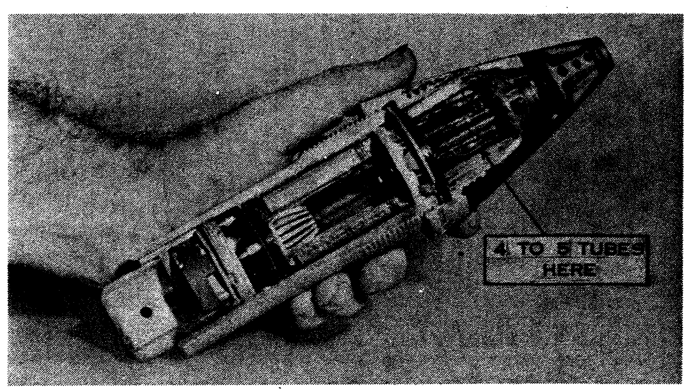
The first extensive use of the proximity fuze over land was over England where it proved far more effective than fighter planes in combating the V-1 bombs launched against Southern England. The fuze was used by the British in 3.7" anti-aircraft guns and by the United States Army in 90 mm. batteries.

The use of the fuze was next authorized for the anti-aircraft defense of the artificial harbors along the Normandy Beachhead. As the anticipated enemy air attack over these targets failed to develop, these batteries did not see action.

The fuze was released for general use over land on October 25, 1944, and was used extensively in howitzers against infantry in Italy and in the Battle of the Bulge. The tremendous effectiveness of the fuze against concentrated infantry is indicated in a letter from General Patton in which he reported 702 individuals killed from one German battalion. During this period the Army also used the fuze extensively in anti-aircraft action against German planes on the Continent and in the defense of the Harbor of Antwerp against concerted attacks of V-1 flying bombs. This record indicates the tremendous strategic value of the weapon in the recent war.

OPERATION OF THE FUZE

The radio proximity fuze comprises a combination radio transmitter and receiver housed in a plastic case which forms the nose of the projectile to be shot from a cannon. In shape it is similar to the housing of other fuzes, since, of course, the ballistics of the projectile must not be altered by the fuze housing. Imbedded in the tip of the nose is a small piece of metal which con-



Courtesy Sylvania News

Fig. 1 - Proximity Fuze

stitutes the antenna both for the transmitter and the receiver. The oscillator circuit supplying the transmitter with radio power is so designed that its operation is strongly affected by receiving radio signals reflected back by any target. This effect is amplified and fed to a thyratron tube which triggers a very sensitive fuze. This fuze is surrounded by a small charge of special powder, which, on being set off, in turn sets off a larger charge which again, in turn, sets off a still more powerful charge. This last is called an "auxiliary detonator", and it is this which actually sets off the high explosive of the shell.

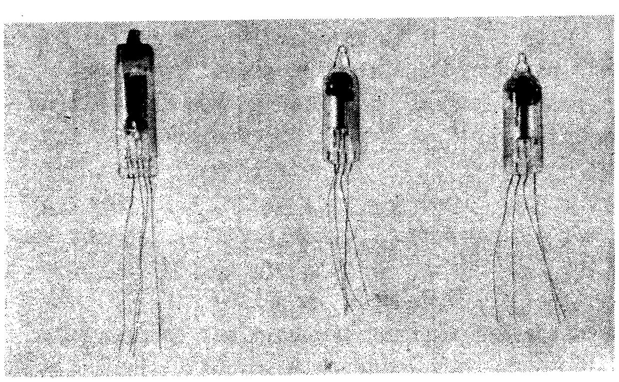
To make the fuze thoroughly effective, it is important that the radiation pattern of the radio transmitter have the proper correlation with the fragmentation pattern of the exploding shell. When this relation has been achieved, any projectile passing within lethal distance of a target will explode and shower the target with high speed fragments.

The proximity fuze is, of course, elaborately protected with safety devices to make handling safe and to prevent muzzlebursts. These devices are both electronic and mechanical.

Other features of the proximity fuze provide for self-destruction in the air for such anti-aircraft shells as may not approach or pass the target sufficiently close, and in types used against land targets for explosion on contact in case the radio fuze fails.

RUGGED TUBES

All the components of the fuze must, of course, be made extremely rugged to withstand the great forces developed in being fired and in flight, as referred to previously. From the point of view of "ruggedizing" to the point of withstanding the forces of being fired from a gun, the most spectacular items are undoubtedly the radio tubes.



Courtesy Sylvania News

Fig. 2 - Vacuum Tubes used in Proximity Fuze

Two methods of attack were followed from the outset in the development of these tubes. One was a cut-and-try technique in which the then available types of tubes were fired first at low and later at higher accelerations. After being shot, the tubes were recovered and on the basis of breaks that occurred changes in the design were made. The other development technique was an attempt to design the necessary rugged structure in the form of a wholly new tube design.

The first method was applied principally to tubes of the hearing aid type, such as those produced in pre-war days by Raytheon and Hytron. The second method was first applied in the Bell Telephone Laboratories and later at the Sylvania Plant.

In view of the fact that it was so commonly believed the task of "ruggedizing" a tube to withstand firing from a gun was impossible, it was desirable to have many independent lines of development proceed at one time. Consequently, RCA was commissioned to develop a metal tube of the desired ruggedness. Later in the program, Ken-Rad was asked to design a metal tube that would incorporate all of the experiences gained by other manufacturers. The General Electric Company was also engaged in the development of a special type of oscillator tube.

Many of these developments resulted in the production of tubes of the required ruggedness. Sylvania and Raytheon tubes were the first to reach large scale production. This fact weighed heavily in the adoption of tubes as manufactured by these two companies. In the later days of the war Raytheon expanded its efforts along other lines and Sylvania remained as the sole supplier. Some idea of the magnitude of the operation may be gleaned from the fact that by June of 1945 Sylvania was producing tubes at the rate of approximately 400,000 per day, and plans were under way for increasing production to 525,000 per day. It is interesting to compare this with the fact that before the war about 600,000 radio tubes per day of all kinds were made by all companies in the United States.

THE TESTING OF RUGGED TUBES

One of the more interesting techniques that contributed greatly to the development of tubes of the necessary ruggedness was the method of testing and recovery. In this testing, tubes were loaded into cavities in plastic blocks which, in turn, were loaded into hollow shells. The shells then were fired almost vertically from a high speed, rifled cannon. These projectiles were fired at an acceleration of 20,000 g and with a higher spin than that produced in the Navy anti-aircraft guns. In these tests the excessive acceleration and spin provided a margin of safety over the conditions of actual use.

In the matter of recovery, it will be noted that when a projectile is fired nearly vertically into space it returns to the ground without turning over in the air, sinking into the ground for a distance depending on the nature of the soil. Thus, in practice, observers in two or more locations observe and note the small cloud of dust made as each projectile enters the ground. When the firing has been completed a ground crew, equipped with post hole diggers, dig out the shells. These shells are then returned to the laboratory, disassembled, and the tubes are examined for glass breakage, etc. All unbroken tubes are then tested electrically. Any tube whose characteristics differ from its pre-shooting values is cut open and examined for defects with the aid of a microscope.

These techniques of testing contributed greatly to the early development of the tubes of the required ruggedness. They were continued as a production test right up to V-J Day.

MICROPHONICS

The tubes produced for the proximity fuze were not only the most rugged tubes ever to have been manufactured, but were also the least microphonic. In the development of this characteristic, tubes were mounted on the driving mechanism of a large loudspeaker system and the latter was driven by an alternating current supply of widely varying frequencies. In this manner the motion of individual vibrating elements in the tube was greatly accentuated. Visual observation of the offending element was then made by viewing the tube structure through a low power microscope while illuminated by a stroboscopic light source of controllable frequency.

TESTING OF COMPLETE FUZES

In addition to testing tubes by shooting, completed fuzes were also tested in this manner. The standard technique was to shoot projectiles at a medium-high angle over water. The shells would then explode as they approached the water. This method not only permitted a daily check on the percentage of shells that were operable, but also provided quantitative data on the sensitivity of the fuzes as the height above water at which the explosion occurred could readily be determined and noted.

Testing of completed units was accomplished by shooting against wire netting suspended from a captive balloon. In most of these tests only a small charge of black powder was used, as this provided the necessary visibility of the burst while not damaging the target at more than a moderate rate. It is interesting to point out that in some of the earlier tests high explosive shells equipped with proximity fuzes were fired at radio controlled planes. Happily for the success of the war effort, the effectiveness of the proximity fuze made this type of testing far too expensive.

FUZE DUE TO VAST COOPERATIVE EFFORT

In an account of an achievement of this order of importance, one would like to credit all the individuals that made the more important contributions. Such a task is extremely difficult. In the first place, the number of those employed in the OSRD Laboratory charged with the development of the device and in the collaborating industrial plants is extremely large. Secondly, it is difficult, if not indeed impossible, to properly appraise the work of individuals who have all worked together so cooperatively. The news releases have mentioned the name of the Director of the OSRD Laboratory responsible for the development, Dr. Merle A. Tuve. He was a dynamic leader whose combined vision and drive were in a large measure responsible for the success of the project as a whole.

With respect to the development of the rugged tubes necessary for the successful development of the proximity fuze, many men in the cooperating companies merit much credit. The greatest individual contribution to the development of the necessary rugged tubes was made by Dr. R.D. Mindlin. He was on leave from Columbia University and was in the Electronics Section of the OSRD Group which developed the fuze. Dr. Mindlin, himself, was responsible for much of the original design work. In addition, his leadership in enlisting the active cooperation of men in the industry played a large role in the development.

RADAR COUNTERMEASURES: THE SCIENCE OF IMMOBILIZING ENEMY RADAR

by

OSWALD G. VILLARD, JR.*

INTRODUCTION

One of the largest electronic equipment development programs carried out during the war was concerned with putting enemy radar out of action. This was done very successfully - at crucial moments during the war our enemies were deprived of the use of this important weapon. It can be said that the Allies used radar and got the most out of it; the enemy used radar and got very little out of it. Over three hundred million dollars' worth of radar countermeasures equipment was ordered by the United States prior to V-J Day. Virtually unheard of before Pearl Harbor, radar countermeasures were, by the end of the war, part of the standard equipment allowance of every ship of the United States Navy, and every heavy bomber of the United States Army Air Forces. Countermeasures gear was carried aboard many patrol bombers and many carrier-based aircraft as well.

Yet, all of this apparatus had been developed, manufactured and introduced after the war began - after the United States had definite enemies and a definite order of battle in mind. The largest portion of the research and development was carried out under Division 15 of the National Defense Research Committee - the third largest Division (in terms of money expended) of that organization. By far the largest contractor of Division 15 was Harvard University's Radio Research Laboratory, founded early in 1942 and located only a mile away from the NDRC radar development project at the Massachusetts Institute of Technology.

ENEMY RADAR

Our enemies were not slow to appreciate the importance of radar. True, the Germans were somewhat behind the British in the application of this weapon, but this was consistent with their original idea of a "short", offensive war. When forced on the defensive, the Germans rushed to completion formidable chains of radars, capable of giving advance warning of air or sea attack, of directing coastal defense or anti-aircraft guns under blind conditions, and of helping night fighters to find their prey in the dark. With the help of these detectors they hoped to turn back allied bombing by air, as well as allied invasion by sea.

German radars included 100-200 megacycle air-warning sets; 375 megacycle air-intercept sets (for antennas used with this equipment, see Figure 1); 400 megacycle coast-watching and fire-control equipment, and 500-600 megacycle anti-aircraft fire-control sets (see Figure 2). Every one of these radars was successfully and systematically jammed by the allies.

By comparison the Japanese had inferior radar gear; their best sets were copies of low-frequency British and American equipment captured during the early days of the war. These included airborne ship-search, as well as anti-aircraft fire-control

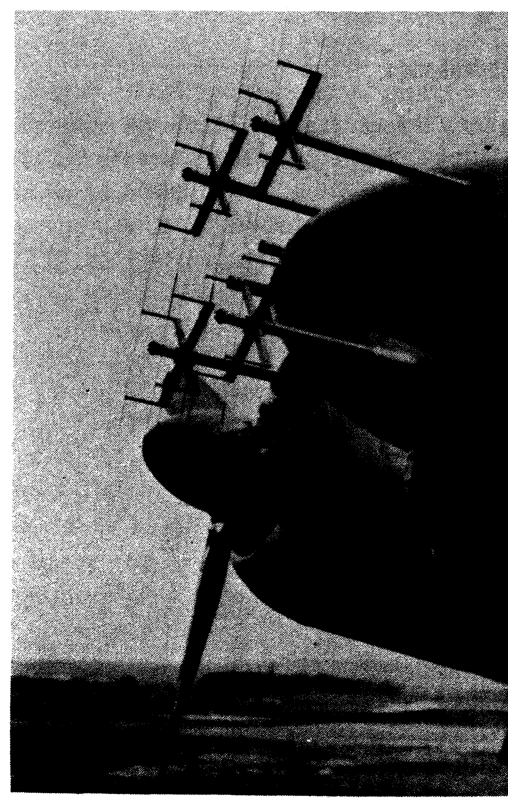


Fig. 1 - Air-Intercept Radar Antennas on the Nose of a German JU88 Night Fighter.

*Radio Research Laboratory, Cambridge, Massachusetts.
A paper delivered at the January, 1946 meeting of The Radio Club of America, New York City.

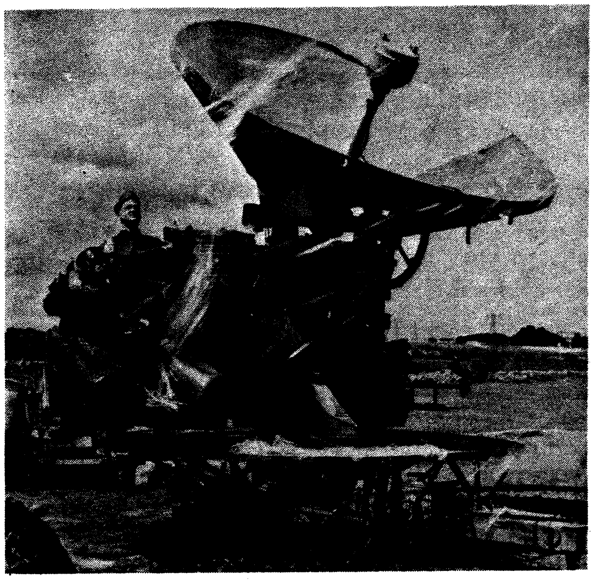


Fig. 2 - American Soldiers, Operating a Captured German Anti-Aircraft Radar of Standard Design, Graphically illustrate the Effects of Metal Foil Strips known as "Window".

sets. All suffered the same fate as their German counterparts.

RADAR'S WEAKNESSES

Briefly, a radar is vulnerable to countermeasures because (1) it transmits tremendously strong radio pulses which can be heard at distances far greater than those from which it can receive back an echo, (2) like all radio stations, it can be located by radio direction finders and marked for later destruction, (3) since the echo it receives is always weak, the "pip" from a target can be concealed by a relatively low-power jammer (order of 10 watts) carried on that target, and (4) since it cannot determine the precise nature of a target, it cannot always distinguish between real targets and decoys.

COUNTERMEASURES DEVELOPED

To exploit the first of these weaknesses, "search receivers" were developed (see Figure 3) which are remarkable for the wide frequency range covered by plug-in, interchangeable tuning units. Four such units are provided with the receiver illustrated, making continuous tuning from 30 to 3000 megacycles possible. As simple to operate as a home radio (oscillator and mixer tuning are ganged by means of an ingenious cam arrangement) and provided with a high-frequency, wideband intermediate frequency amplifier, these sets should be ideal for pulse communication and television receiving purposes. Special microwave intercept receivers equipped with tunable lighthouse tube local oscillators and capable of operation at frequencies substantially higher than 3000 megacycles, were also developed.

As attachments for these receivers, wideband direction finding antennas were developed. One, a simple null-type device, consists of a remotely controlled balanced dipole for horizontal polarization, plus an Adcock array for vertical polarization. Designed for airborne use like most countermeasures equipment (including much used aboard ships), this direction finder covers the range 70-450 megacycles with four interchangeable heads. Another, more complicated set displays instantaneous bearing information on a cathode ray tube screen, and is thus very suitable for the higher frequencies where signals from narrow beam, rapid scan radars are received in periodic bursts. This direction finder in effect plots the polar pattern of a rapidly rotating directional aerial

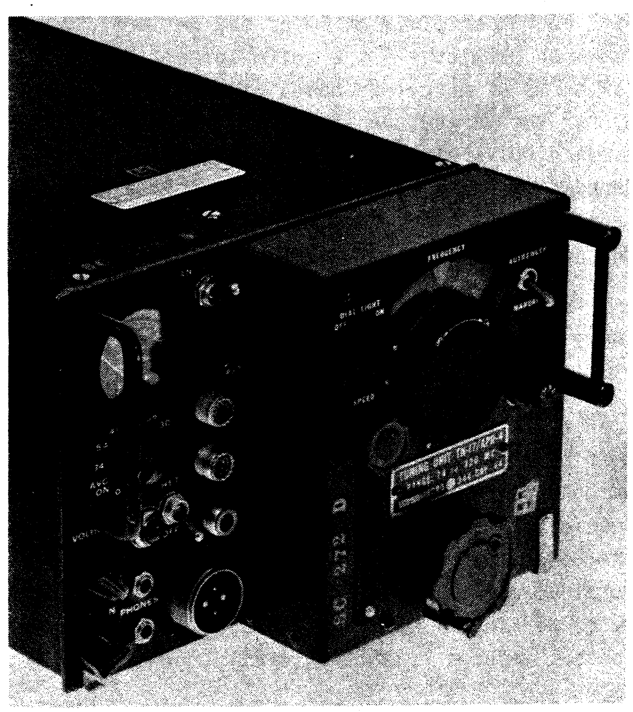


Fig. 3 - Standard Radar Search Receiver: Tunes from 30 to 3000 Megacycles by Means of Plug-In Tuning Units.

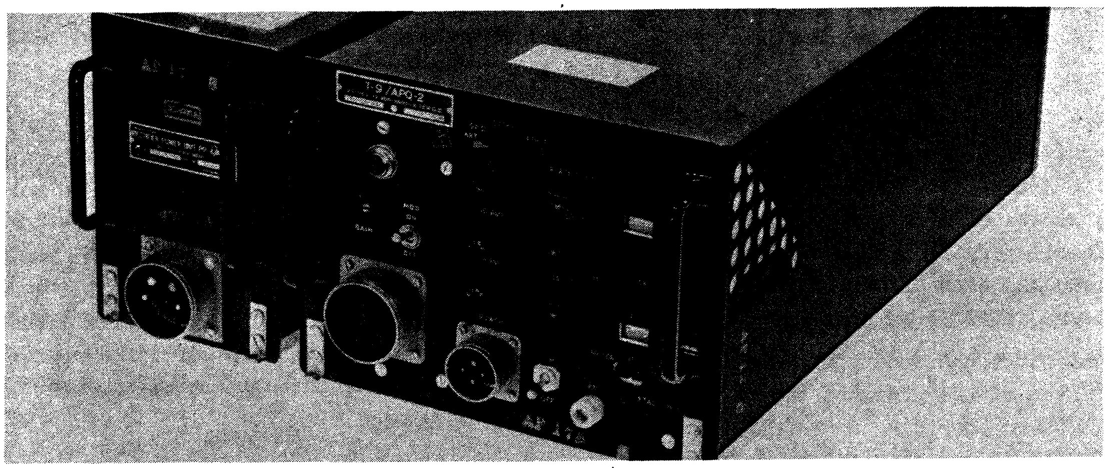


Fig. 4 - One of a Line of Standardized Radar Jammers; Known as "RUG", This Set Tunes from 200 to 550 Megacycles.

on the cathode ray tube; the pattern being automatically aligned with the antenna in such a way that the position of the displayed lobe corresponds to the bearing of the unknown radar station. Direction finders such as these, used in connection with ultra-high-frequency beacons or other services, may provide a simple solution to peace-time navigation problems.

Radar jammers are designed to operate over the widest possible frequency range (since the enemy may shift the operating frequencies of his radars), and to produce the maximum possible power output for a given weight and volume. The jammer shown in Figure 4 will operate anywhere between 200 and 550 megacycles, with a power output of some 20 watts. It was designed especially for use against the German coast-watching radars. Some of these jammers protected our assault craft during the landings at Salerno. Note the standardized packaging, characteristic of almost all RCM equipment. By using the "Standard Aircraft Rack", installation of new gear in already operating ships and aircraft was greatly simplified.

The most effective type of modulation for radar jammers was found to be wideband random noise. Most jammers are simply oscillators modulated by such a signal. The effect on a radar is to raise the background noise level of the re-

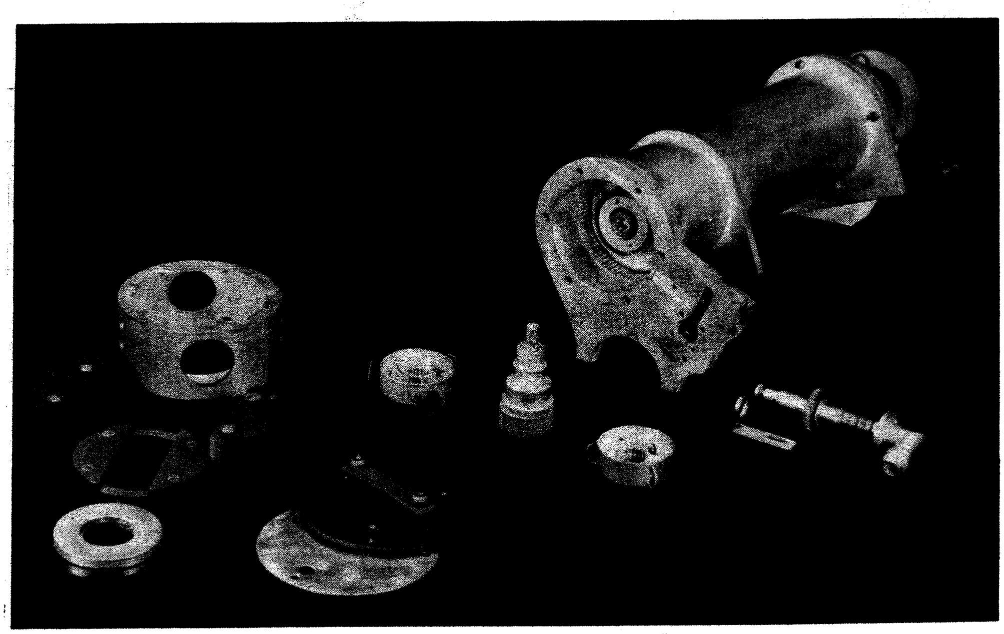


Fig. 5 - Exploded view of a High Power Lighthouse Tube, Concentric-Line-Type Oscillator. Tunes from 300 to 2500 Megacycles.

ceiver, thus reducing the signal-to-noise ratio. The only counter-countermeasure is to change the frequency, which is not always easy to do in a complicated radar system. Remarkably efficient sources of high level random noise were found; the 931 phototube was widely used at first, but it was replaced by a 604-D gas tube operated in a magnetic field. Wideband noise sources such as these will find peacetime application for receiver noise figure measurements, production alignment of double peaked amplifiers, etc.

The bandwidth of the spectrum radiated by most jammers being of the order of several megacycles, it was found possible to "barrage" a sizable portion of the radio spectrum by setting a number of jammers each, say, one megacycle apart. This procedure proved particularly effective in the case of the 12- and 18-plane formations flown by the 8th Air Force in Europe. Eighteen jammers, carried one-to-a-plane, could easily blanket the 10 or 15 megacycle band in which the German antiaircraft fire control radars were operating at first. Later, both the German's operating band, and our "barrage" band, were considerably extended.

As a result of jammer developments carried out by the Radio Research Laboratory, as well as vacuum tube research and development carried out by industrial contractors of NDRC Division 15, the power output of production airborne jammers for the German 560 megacycle band was increased, during the war, from an original 5 watts, to more than 150 watts of power. Moreover, this large power output is capable of being spread over a 30 megacycle band, if desired. The source of this energy is a water-cooled, split anode magnetron tube. For shipboard use, tubes similar in principle, but with a power output of over one thousand watts, were developed.

Nor were triode tube types neglected. Figure 5 is an "exploded" view of a high power, concentric-line lighthouse tube oscillator, tunable over the phenomenal frequency range of 300 to 2500 megacycles! Power output is of the order of 25 watts. It can be said that the present development of high power lighthouse tubes is due in large part to their application in countermeasures equipment.

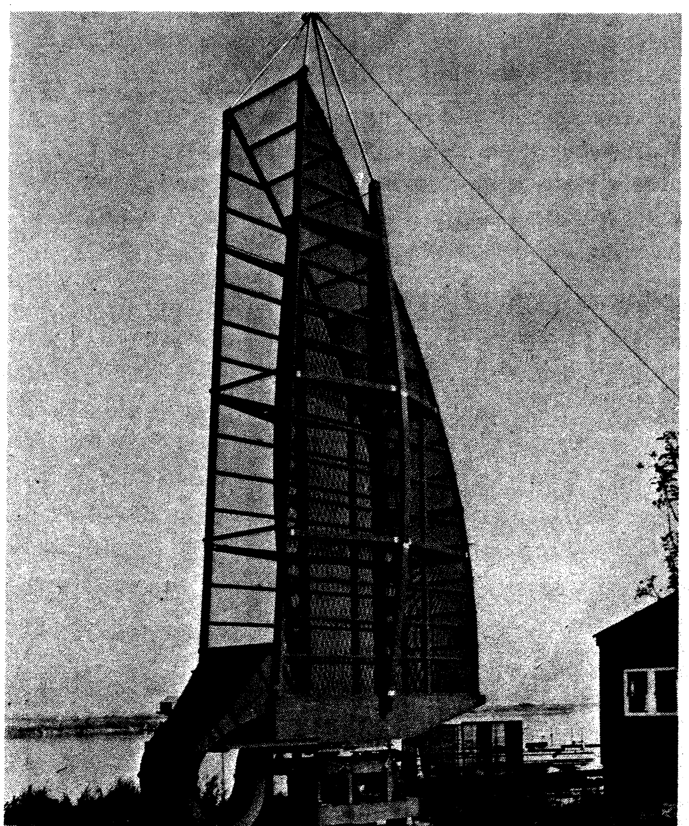


Fig. 6 - Wideband Horn-and-Reflector Type Antenna for the Resnatron Jammer.

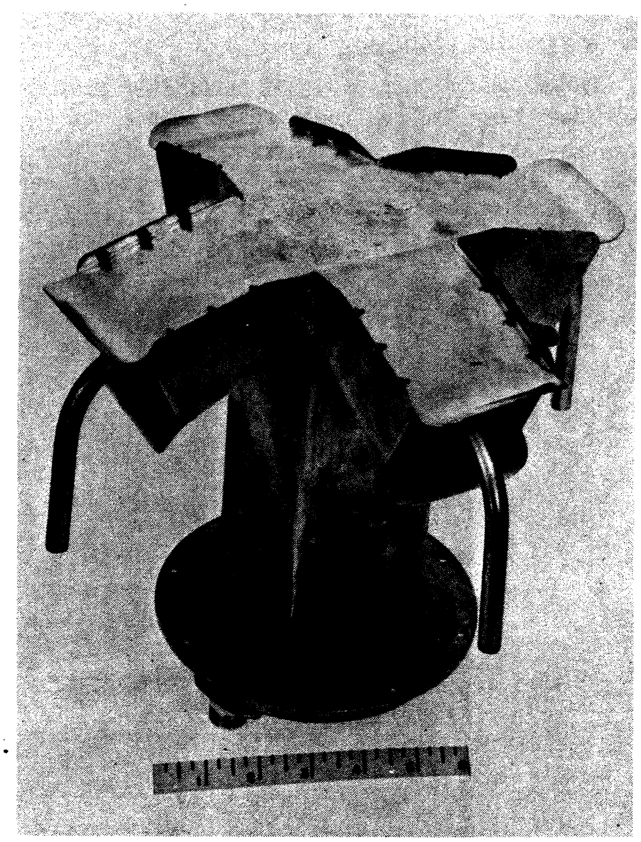


Fig. 7 - Wideband Circularly-Polarized Jammer Antenna: Useful Against Radars of any Polarization.

In the 10-centimeter region, multiple cavity, continuous-wave magnetrons of several power levels were developed. For airborne jamming applications, a series of 50 watt tubes, tunable over a 15 percent frequency band, have been realized. For ground-based or shipboard work CW powers of over one kilowatt have been achieved.

Perhaps the most remarkable achievement of all, however, is the Sloan-Marshall or "Resnatron" tube, once (before the British magnetron) the white hope of United States radar designers. This tube, invented at the University of California and perfected by the Westinghouse Electric Corporation, was incorporated by RRL in a high-power, ground-based jamming system to counter the German night-fighter radars. Capable of a continuous power output of the order of 50 kilowatts at 500 megacycles, this jammer was used to lay down a tremendously strong "beam" of jamming over Germany - a path in which the black-painted JU88 night fighters were blinded when they tried to intercept homeward flying British bombers.

A wideband antenna used with this jammer is shown in Figure 6. Note the 22 by 6 inch waveguide feeding the horn at the base of the giant reflector. Resnatrons have been built for operation anywhere from 350 to 600 megacycles; their high frequency limit is around 700 megacycles. Since the input and output circuits of this tube are coaxial cavities fully shielded from each other, the Resnatron can be used either as an oscillator or as an amplifier. Modulation bandwidth is limited by the "Q" of the cavities; however, a one or two megacycle band has been achieved without difficulty.

Wideband antennas had to be developed to go with the wide-tuning-range search receivers and jamming transmitters. These took the form of thickened stubs, cones, or "sleeve" antennas depending on the application. An example of the latter is shown in Figure 7. This odd affair radiates a circularly polarized field, (i.e. it will jam radars of any polarization), and was designed for use against the German anti-aircraft fire control radars. The "sleeve" design permits operation over an unusually wide frequency range (25% or more) with a maximum standing wave ratio on the transmission line of two-to-one. For receiving purposes, where a maximum voltage standing wave ratio of 4 to 1 is tolerable, cone antennas capable of operation over a 10 to 1 frequency range have been designed. An even more interesting development from the post-war point of view, is the so-called "slot" antenna which requires no protuberance outside the skin of the airplane on which it is mounted. These antennas, of quite reasonable dimensions for frequencies above 1000 megacycles, should prove ideal for the new jet-propelled and jet-assisted aircraft where conventional "blister"-covered radiators are not acceptable.

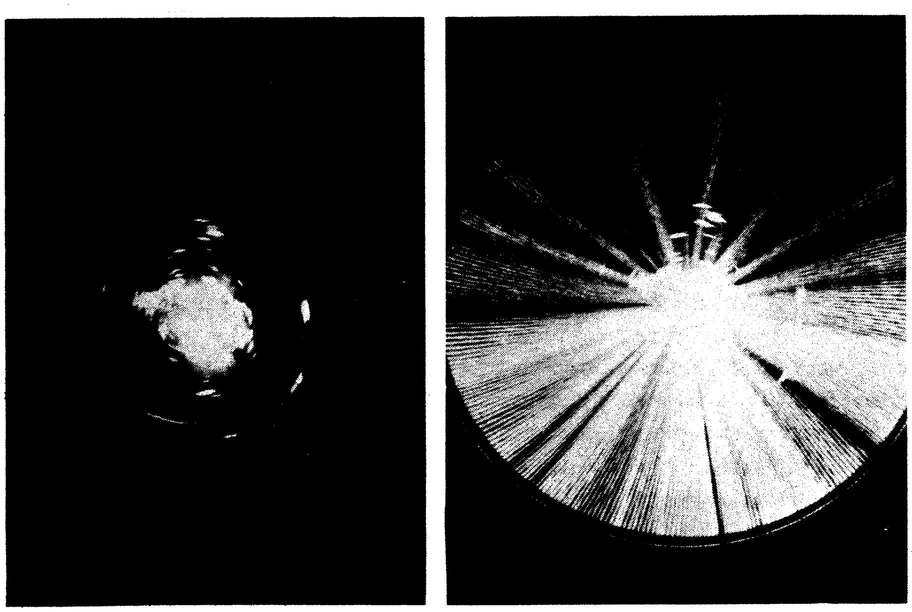


Fig. 8 - Left - Normal PPI-Type Radar Scope: Right - Same with Jamming Present

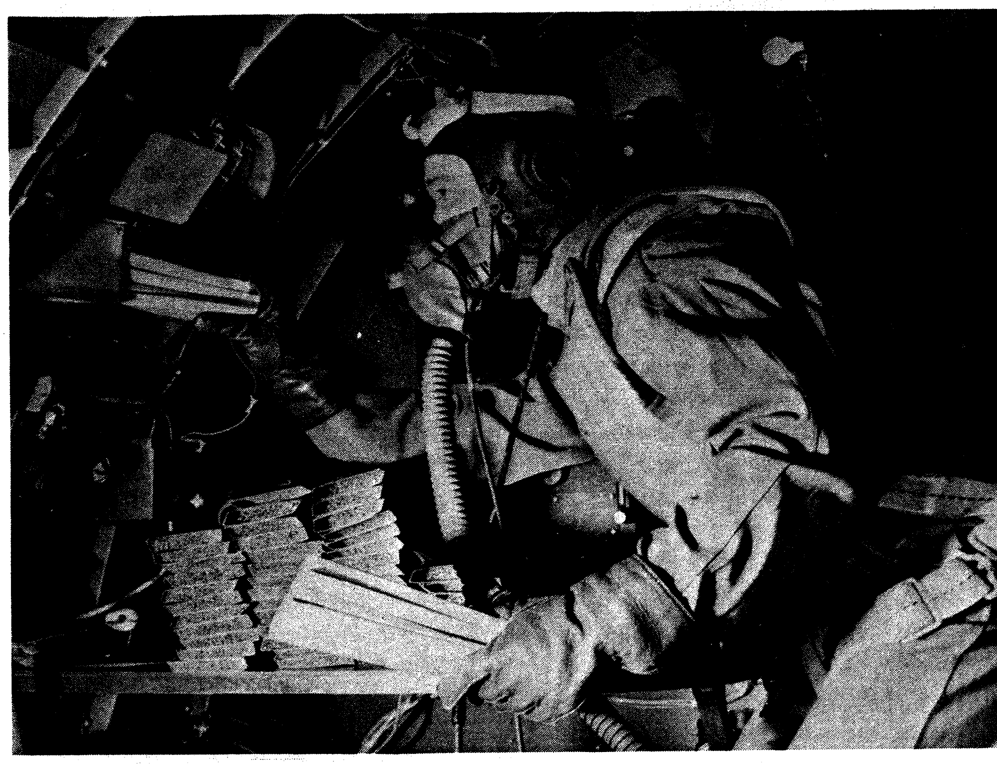


Fig. 9 - Air Crew Member Ejecting Bundles of "Window" from B-17 Bomber

It is interesting that countermeasures equipment, designed in war-time for an essentially destructive purpose, should nevertheless be in many instances almost directly applicable to post-war communication problems. This is because countermeasures tubes and transmitters had to be designed for continuous wave, rather than pulsed service.

The effect of jamming on a typical microwave radar scope is shown in Figure 8. Strong jamming will be visible in all sectors of the Plan Position Indicator because some energy will always be picked up by the back lobes of the radar beam.

It was realized early in the war by both the Allies and the Axis, that many thousands of strips of tinfoil, acting as parasitic antennas, would be capable of reflecting a strong signal back to a radar. Both sides considered this countermeasure so dangerous, that extreme security precautions were taken. For example, the German High Command made no effort to warn either scientists or radar operators of the effects of tinfoil - called "Window" - prior to the first British use of this countermeasure in August, 1943. As a result, the Germans were taken by surprise and lost valuable time in devising counter-countermeasures. The British, meanwhile, had refrained from using Window until adequate numbers of microwave radars (less susceptible to tinfoil because of their narrow beamwidths and short pulse lengths) were on hand.

Figure 9 shows a crew member of a B-17 bomber ejecting bundles of Window from a specially designed chute in the radio room. Each bundle contains over two thousand strips, weighs about two ounces, and returns an echo equivalent to a four-engined bomber.

Approximately seven hundred of these bundles would be dispensed by our heavy bombers during a typical mission, with the results shown in Figure 10. The two photographs, taken from a captured German training film, show the appearance of the scope of the radar illustrated in Figure 2 before and after the use of Window. The left-hand picture shows the echoes from a formation of Allied bombers at approximately two-thirty o'clock. On the right-hand side, we have the effect produced by a trail of Window over 25 kilometers long. The Germans found out that tracking aircraft through this clutter was very difficult if not impossible.

In order to relieve crew members of the necessity of tossing the bundles out by hand, automatic dispensers were devised, one of which is shown in Figure 11. Slung under the wing of a fighter in the same manner as an expendable gas

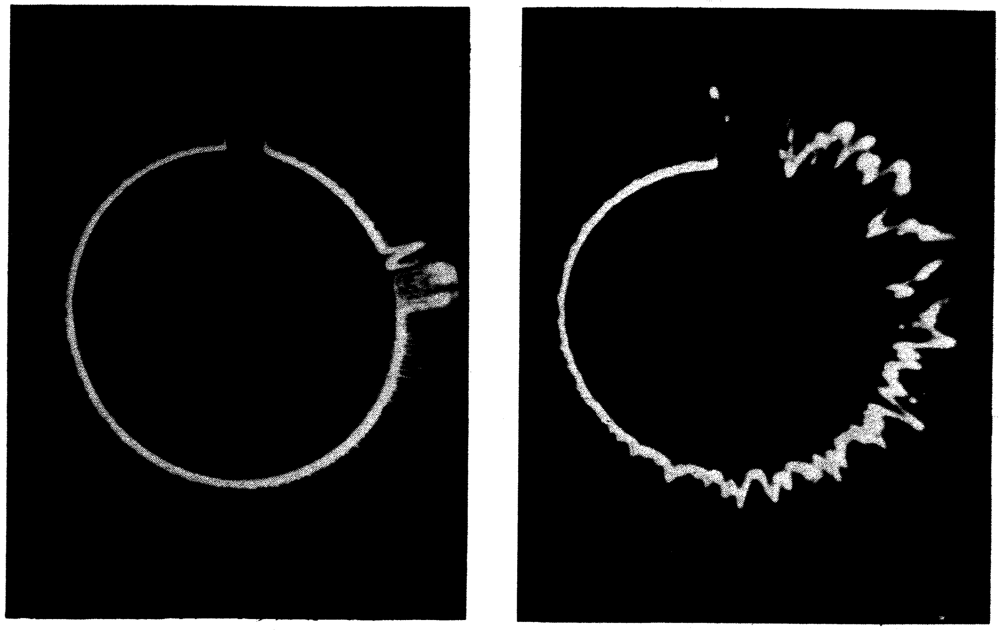


Fig. 10 - German Radar Scope, Before and After "Window". From a Captured Enemy Training Film.

tank, this Window "bomb" ejected its bundles at a predetermined rate and could be jettisoned when empty. Fast fighters were often used to drop Window over heavily defended targets in order to confuse the enemy gunners before the main raid arrived. In all, some 10,000,000 pounds of metal foil were dropped on Europe by the 8th Air Force alone. United States foil manufacturing capacity was trebled during the war. Of the total output, over 75% was devoted to the production of Window.

COUNTERMEASURES IN THE WAR

Only two months after the British began using Window during their night bombing operations, the United States 8th Air Force introduced regular electronic jamming. By December, 1943, the 8th Air Force was using both jamming and Window. This program was well-timed. The Germans ended the war with over 4,000 anti-aircraft radars in service - radars which controlled some 16,000 guns ranging in size from 88 mm. to 128 mm. One of the latter, captured at Ploesti, is shown in Figure 12. Capable of firing shells to an altitude of 50,000 feet, these guns were thoroughly respected by our aviators. The white rings on the barrel of the one illustrated indicate the number of allied planes it was supposed to have shot down.

Late in 1943, the 8th Air Force introduced radar bombing, or bombing through the overcast. As a result, the average number of days per month on which operations were possible rose from 9 in 1943 to 22 in 1944. At the same time German fighter strength declined. By the summer of 1944, bomber losses and damage due to flak were three times as great as those due to fighters, whereas one year before the situation had been exactly the reverse. The helplessness of the Germans in the face of our "blind" air attacks may now be pictured. With their fighter defense neutralized by our long range P47s and P51s, they had no other defense against bombs through the overcast than radar-controlled anti-aircraft fire - and their radars were jammed! After V-E Day, United States investigators determined that during the critical months from September, 1944 until the end of the war, the effectiveness of German radar-controlled anti-aircraft fire was no more than 25% of normal! It can be shown that during this period, over 450 bombers and 4,500 casualties were saved by countermeasures in the 8th Air Force alone. Roughly, the same considerations applied in the case of the 15th Air Force, about one-half the 8th Air Force in size.

The task of fitting out our bombers with the necessary jamming equipment was no small one: of

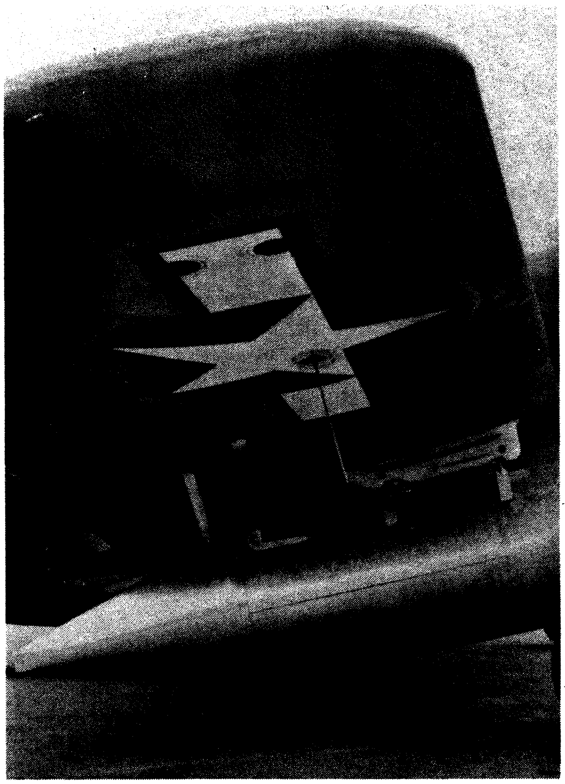


Fig. 11 - Expendable "Window" Dispenser Mounted on a Fighter.

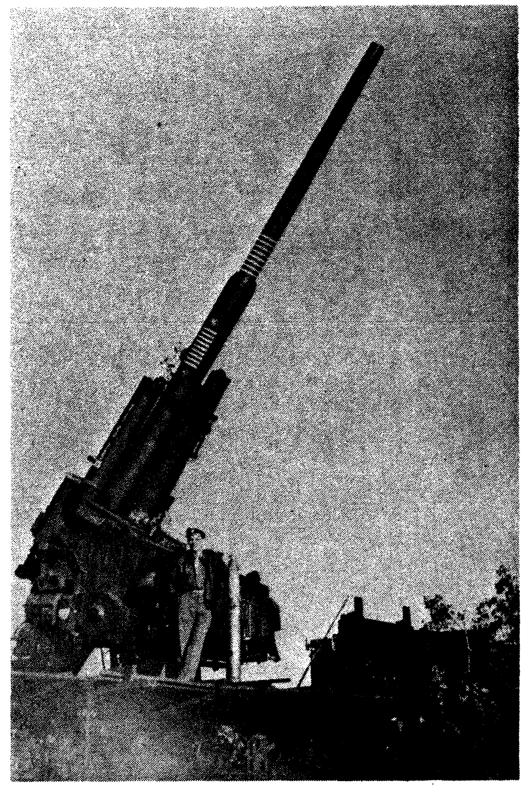


Fig. 12 - German 128 MM. Anti-Aircraft Gun, Captured at Ploesti, Rumania. White Rings on the Barrel are "Kills".

the 8th Air Force's 3,000 heavies, roughly 500 were equipped with three jammers and a search receiver, while 2,000 planes were given unattended installations of two jammers each. All these sets had to be installed in the theater during the intervals when the planes were not on active operations.

Toward the end of the war in the Pacific, when Japanese radar-controlled searchlights and anti-aircraft fire began to be a factor, the Mariannas-based B-29s were also given countermeasures protection. Final plans called for the carrying of 600 pounds of Window, plus two jamming transmitters, in each plane. Certain special aircraft was scheduled to receive no less than fourteen jamming transmitters (controlled by two operators) plus some 2,000 pounds of Window. Carrying jammers meant carrying less bombs, but no objections were raised!

During the invasions of Normandy and of Southern France, the United States and British Navies installed many hundreds of radar jammers and other equipments aboard their vessels in order to prevent German radar observation prior to the actual landings themselves, as well as to protect the ships from radar-controlled coastal gun-fire. Some idea of the importance of this activity may be gained from the fact that the Germans had installed one radar for each one and one-half miles of the Normandy coastline! No less than 12 different types of equipments had to be dealt with.

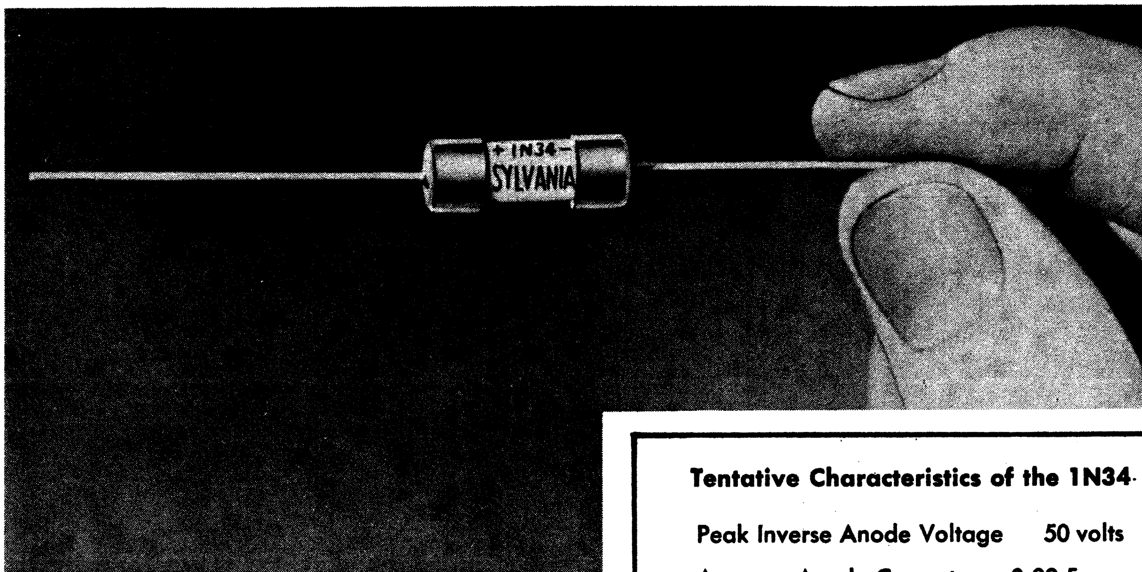
Prior to the amphibious attacks, naval diversionary forces were sent out to put the enemy off guard. These consisted of small ships, fitted with a certain amount of jamming equipment (enough to confuse the enemy operators but not enough to prevent them from seeing something), plus devices to make the small vessels look like more and larger ones. To this end, radar decoys consisting of balloon-supported corner reflectors made of chicken wire were carried. When viewed by a radar, these reflecting surfaces seemed very large indeed, and the yacht became a "battleship". In addition, large quantities of Window, dropped from low-flying aircraft which circled over the ships, still further enhanced the effect.

Vessels of the main invading forces were given all-out jamming protection, in order to neutralize any fire-control radar which might be encountered. When a United States cruiser, standing off the coast of Normandy, found itself subjected to uncomfortably accurate shore fire, a countermeasures-equipped ship was directed to take its place. As soon as the substitution had been accomplished, and the offending radar located and jammed, the shore fire became inaccurate and soon ceased altogether. A captured German radar operator, unfortunate enough to have been stationed at what became the Omaha Beach, told interrogators that he knew something was coming, but had had no idea what it was.

CONCLUSIONS

The experience of the past war has shown that full reliance can never again be placed on chains of low frequency, relatively wide-beam radars. In a sense, countermeasures have obsoleted an entire class of these devices. Since even microwave sets can be systematically jammed if they are operated close to the same frequency, it is clear that if we are to place much reliance on radar equipment in the future, frequencies of operation <u>must</u> be spread as much as possible in order to make the task of jamming difficult. Moreover, it should be remembered that a single radar can always be sought out and countered by the enemy. Where much depends on a particular installation, the threat of countermeasures makes it mandatory that more than just one radar be provided. Thus, radar countermeasures may be said to have made radar protection more expensive.

HERE'S A NEW CIRCUIT ELEMENT
that displays non-ohmic characteristics



Tentative Characteristics of the 1N34

Peak Inverse Anode Voltage	50 volts
Average Anode Current	0-22.5 ma.
Peak Anode Current	60 ma. max.
Surge Current	200 ma. max.
Back Conduction at 50 volts	2 ma. max.

(Surge current refers to transient values; peak current refers to the maximum value of an applied AC signal.)

IMAGINE a circuit element that *violates* Ohm's Law. One that exhibits *polarized* non-linear current-voltage characteristics.

Such an element has now been made commercially available for the first time . . . Sylvania Electric's 1N34 G_x metal Crystal Diode. This tiny unit (shown full size in illustration) opens up many interesting potentialities in circuit design. Withstanding relatively high voltages, it is extremely useful as a circuit element.

Light in weight and equipped with pigtail leads, it is conveniently soldered into place . . . no sockets required. No heater supplies are needed — eliminating hum and noise, permitting both terminals to be connected far above ground potential.

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