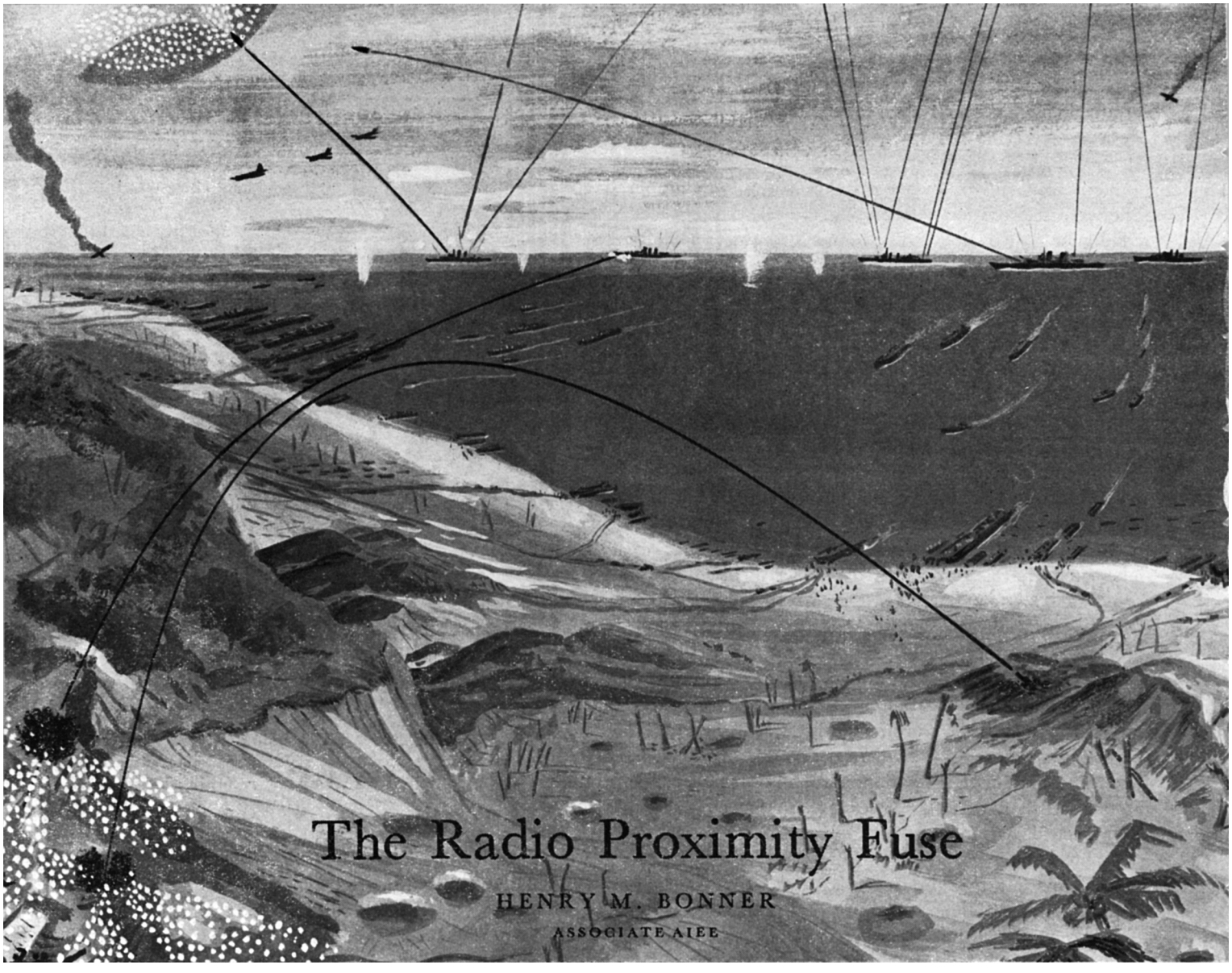


The Radio Proximity Fuse

HENRY M. BONNER
ASSOCIATE AIEE

Courtesy Sylvania

Figure 1. The VT fuse as used for antiaircraft fire and against protected enemy personnel

The fan-shaped area indicates the effective field for fuse action; the dotted areas indicate shrapnel bursts. The proximity field was designed to coincide with the burst patterns

One of the most closely guarded technical secrets of World War II, the proximity fuse was developed to counteract the natural defenses of both the airplane and the infantry. This review of the conception, the construction, and use of the fuse reveals how almost 100 per cent accuracy was built into the artillery of the Allies in World War II.

THE THEME has been expanded that for every weapon there exists a counterweapon, and this fact has been as true in the recent war as in any other. In history, each time a more deadly weapon has been introduced in warfare, another weapon, or a defense, has been developed to nullify its initial advantage. Before the invention of gunpowder, the shield and the suit of armor were partial defenses against the spear and the long bow; but these finally were pierced by the explosively propelled bullet, and the fortifications of the medieval castle crumbled at the impact of the cannon.

Henry M. Bonner, formerly with the Eastman Kodak Company, Rochester, N. Y., is now a graduate student at Columbia University, New York, N. Y.

A weapon new to the first World War was the airplane, opposed by other airplanes and by antiaircraft fire from the ground. In World War II the airplane, although still bound to the earth's atmosphere, was brought, from our present point of view, to a high degree of perfection and of effectiveness. That effectiveness, however, was limited drastically by the development of more efficient techniques of antiaircraft defense, including radar tracking of the target and the proximity fuses.

PROXIMITY FUSE

The proximity fuse, as a method of projectile control, also has limited the usefulness as a defense of a simple hole

in the ground, the much publicized foxhole of World War II. Both the airplane and the bank of earth, one an offensive weapon, the other a defensive one, have been counteracted by an idea made practical by Anglo-American scientists and American industry. The idea demanded the building of a radio transmitter and receiver, small enough to be mounted, along with its energizer or battery, in the front end of a high-explosive projectile, and strong enough to withstand the shock of being fired from a gun at 20,000 times the acceleration of gravity.

LIMITATIONS OF A MECHANICAL FUSE

In antiaircraft use the limitations of a mechanical time fuse, which must be set before firing and which must employ absolutely uniform powder charges, are readily evident. Even though a device had been developed to set the mechanical time fuses automatically on the basis of information supplied by the gun director, the positive action of a proximity field fuse had the advantage of eliminating the necessity of setting the fuse and made its action independent of gun charge or inaccuracies in the mechanical timing mechanism.

For howitzer use, proper adjustment of timed fire requires the firing of about 15 experimental rounds to obtain air and ground bursts, so that the fuse setting can be determined. Valuable time and ammunition are wasted with this procedure, and the enemy is warned to retire from the target area before the fire becomes effective.

Proximity fuses in this application have made foxholes and trenches untenable and have destroyed the protection of revetments. With the proximity fuse, uniform bursts 20 or 30 feet above the ground can scatter a deadly hail of fragments over the surrounding terrain from the first round. The fuses thus have increased the efficacy of missiles from 10 to 20 times. If one fighter can punch ten per cent harder than his opponent the fight is won; if he can punch ten times as hard. . . .

GERMAN RESEARCH

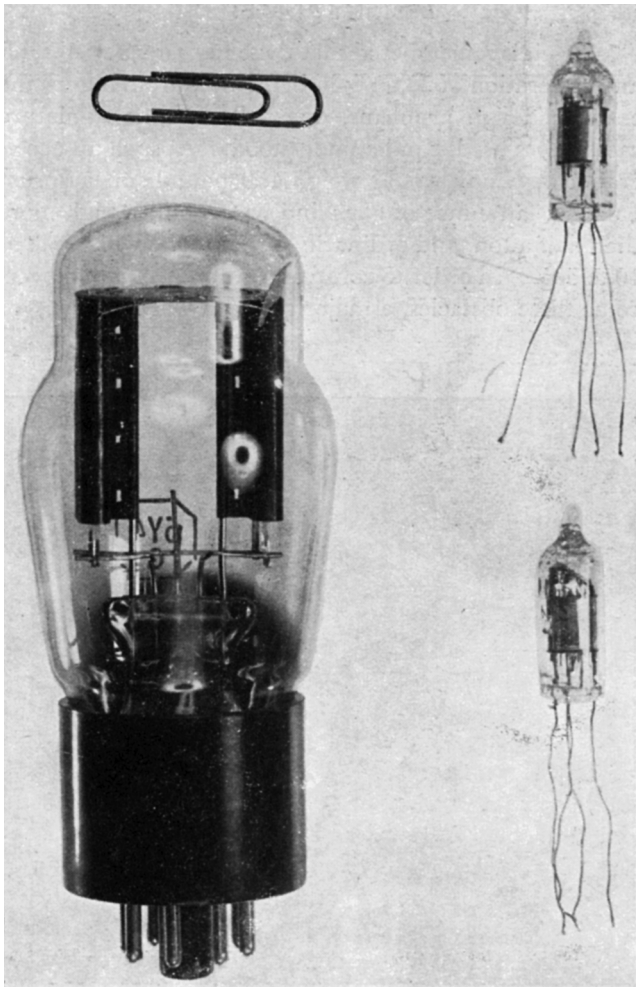
Enemy interest in a proximity fuse was shown in the 1942 spy trials which disclosed that the Nazis were trying to find out whether the Allies possessed such a device. Only too well aware of the potentialities of a proximity fuse, the Germans themselves had started work on the idea as early as 1930; but no design ever was put into quantity production. A multiplicity of fuse types and of groups working on them, combined with a lack of cooperation between the respective groups and between the civilian groups and the military, led to the failure of their program. The Germans were working on acoustic, electrostatic, radio, and 30 other types of fuses, which incidentally were considered only for rockets and bombs. Apparently no German was fool enough to consider firing radio tubes from a gun. For this combination of reasons the Germans were well behind the Allies in their program.

ANGLO-AMERICAN APPROACH

In the United States, the National Defense Research Council, later the Office of Scientific Research and Development (OSRD) was requested to investigate the possibilities of making a proximity fuse, and the attack was conducted along two independent lines with the purpose of simplifying the question of supply and of administration. The Navy sponsored the development and procurement for both services, and for the British, of fuses for howitzer, antiaircraft, and heavy rifle use (75 to 240 millimeters—anything between about 3 and 10 inches); the Army undertook the same problem for all bomb and rocket type fuses. These fuses were known as *VT* fuses by the Navy and *POZIT* fuses by the Army.

Two approaches were considered and developed successfully, although only the second of these actually was put into large scale production or use:

1. Pulse fuse.
2. Radio or proximity field fuse.



National Bureau of Standards photo

Figure 2. Compactness of the tubes manufactured for the proximity fuse (right) as contrasted with the conventional radio tube (left)

The first of these fuses is controlled remotely from the ground by radio. When shell and target are observed to be coincident on a radar screen, the fuse is activated and the explosive detonated. The second and most important fuse type radiates a continuous-wave radio signal which upon reflection detonates the shell. The action is thus completely automatic.

Several types of proximity fuses actually were considered and worked upon. These were:

1. Photoelectric (actually put into limited production for rocket fuses, but subject to certain obvious disadvantages, such as variations in lighting conditions).
2. Infrared.
3. Acoustic.
4. Electrostatic (this was the most successful German approach, and some models actually were put into limited production).
5. Radio, depending upon discontinuities of conductivity, dielectric characteristics, and so forth.

The last of these is the one successfully developed and put into mass production in the United States for both British and American use.

DESIGN PROBLEMS

When it is remembered that these fuses must withstand an acceleration of 20,000g in being fired from a gun, the extreme design problems, especially for the miniature radio tubes used, can be understood. At such an acceleration a penny would weigh 130 pounds on a spring balance; an ounce of glass and wire would weigh more than half a ton, and ordinarily a radio tube will break at 10 to 50g. In order to construct a tube that would overcome these obstacles, a major redesign was required, for the weight of the tube elements could be reduced by a factor of only about ten. Under these conditions, the weight of a soldered joint becomes very important.

As has been explained, the Army undertook development of bomb and rocket type fuses, which in general contend with a different set of conditions. As the accelerations encountered are not nearly so great, different mechanical designs resulted; and, furthermore, the high altitudes and low temperatures encountered by high-flying bombers and fighters led to the use of wind-driven generators rather than energizers or batteries of the type used for gun fuses.

All of these fuses, moreover, had to be mechanically interchangeable with the current types.

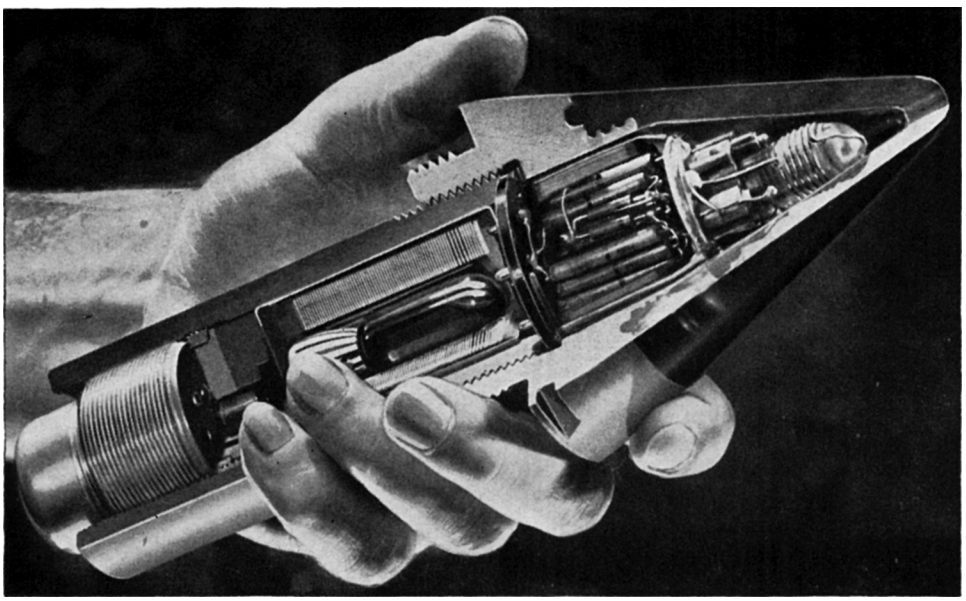
PRODUCTION

Prime contractors for the manufacture of these fuses under Navy contract (for gun use) included, besides The Eastman Kodak Company, which is the only company still in this field, The Crosley Corporation, The Sylvania Electric Company, The Radio Corporation of America, and McQuay-Norris Manufacturing Company. The important energizer suppliers were the National Carbon Company, Eastman Kodak Company (working from National Carbon designs), and Hoover Company.

At the end of the war, The Sylvania Electric Company, which produced about 95 per cent of the tubes used at these accelerations, was producing about 500,000 per day. Before the war, only about 600,000 tubes per day of all kinds were made by all companies in the United States.

Prices also underwent a noteworthy revolution. The first pilot models of these fuses in 1942 and 1943 cost about $40 a piece, exclusive of Government-furnished material, such as tubes and heavy steel parts. Mass production methods cut this cost to $5 or $6 a piece (about $15—$18 including Government-furnished material) and at peak production the various companies produced a total of more than 250,000 fuses per week. As this was a completely new manufacturing problem, contracts were let on a cost-plus basis.

Production was speeded greatly by being broken down into simple easily performed operations, and the complete unit thus was built up from a number of simpler subassemblies. All the resistors and capac-



National Carbon photo

Figure 3. Complete Mark 53 proximity fuse assembly

From the nose down are shown: the radio transmitter and receiver, the batteries, space for the safety switches, and the detonator

itors in the amplifier circuit, for example, first were assembled in a flat form and then wrapped around the rubber sock which contained the tubes (this procedure was initiated at Eastman Kodak and later adopted by several other companies). Waste was reduced to a minimum by the careful screening of rejects, for in the bundle stage (before addition of the radio-frequency section) and in the prepot stage (before potting) the units could be repaired in many instances. After several rejections, however, wear and tear, plus the weakening and breakage of wires, especially the brittle capacitor leads, made salvage impractical, and the units were destroyed.

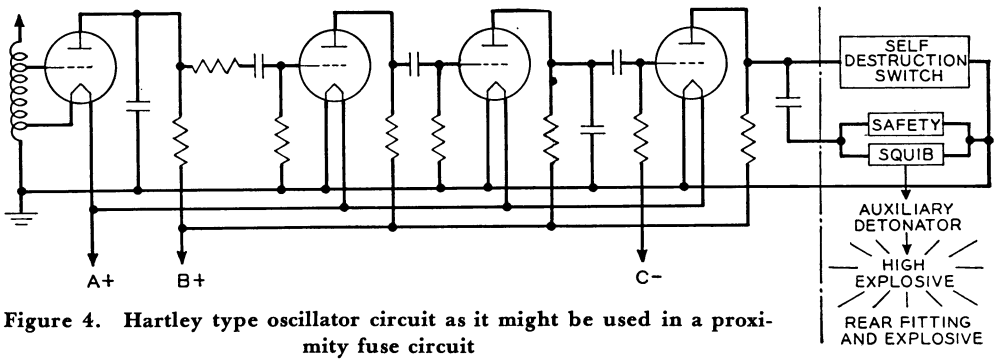


Figure 4. Hartley type oscillator circuit as it might be used in a proximity fuse circuit

SECURITY

Security was, and is, strict on this project. During the war, the very existence of such a device as the proximity fuse had to be kept secret. For this reason, all personnel were investigated carefully, and few people were allowed to know what really was being made, although some of the foremen and supervisors knew or guessed a great deal, as did a few of the workers. Code names were adopted in order to obscure the function of many classified parts. Tubes were called "glass"; capacitors, "tubulars"; and certain terms, such as "oscillation," were not used. Rumors occasionally leaked out, and at various times the project was thought to be making parts for *B-29*'s, dental X-ray equipment, and the like, but secrecy was well kept.

As this was a secret weapon, a most important restriction on the use of *VT* or proximity fuses was the prohibition against using them when duds might be recoverable. This meant, until after the Normandy invasion, that they could be fired only on the high seas, and, as a further precaution, for some time mixtures of mechanical and proximity fuses were used in order to screen the improved performance of the latter and keep its very existence secret. Each and every fuse had to be accounted for under all circumstances, and this made handling difficult. According to one artillery officer, a group in the Battle of the Bulge spent two hours scuffing through the snow hunting for two fuses which finally were brought in by a French peasant woman who had been attracted by the peculiar conduct of the men.

THE RADIO PROXIMITY FUSE IN ACTION

Initial use of the radio proximity fuse in battle came January 5, 1943, when the cruiser *Helena* in the Pacific shot down an attacking airplane with two salvos from two twin-mount 5-inch guns. Wholesale use of the fuses was made by the destroyers *Hadley* and *Evans* in May 1945, off Okinawa. At 7 a. m. a wave of suicide airplanes was spotted; at 7:03 a. m. the first airplane was shot down. Over 150 "kamikaze" airplanes attacked these two ships, and all the attackers were shot down. The *Evans* was struck four times by blazing airplanes or parts; and in one attack on the *Hadley* staged by ten airplanes simultaneously, parts of two hit the deck. Thus, this attack of 150 suicide airplanes resulted in the suicide of all 150 with only six blazing airplanes or parts of airplanes penetrating the screen of *VT*-fused fire. According to an official report, ". . . the horizon from the east to the northwest was full of burning planes. There were too many to count. . ."

Christmas Day 1944 was set as the date of presentation of the *VT* fuse to the Germans, but this date was forced ahead one week by the German counterattack and advance through the Ardennes and by the resultant Battle of the Bulge. After a *VT* fuse barrage, according to an artillery officer who was in the Battle of the Bulge, the forest into which the Allied troops advanced looked as though it had been topped by the sweep of a giant scythe. Tree trunks were shattered and torn; almost every tree was severed about 40 feet from the ground.

Against the robot bombs also, the *VT* fuses proved of great worth. Of 104 *V-1* robot bombs fired in one day, only 4 reached their target, London. Sixty-eight were shot down by *VT*-fused antiaircraft fire; 14 were downed by the Royal Air Forces; 2 hit barrage balloons or their cables; and 16 suffered mechanical failure in flight.

During the later stages of the Pacific war, one third of all bombs dropped from carrier based airplanes were *VT* fused. Iwo Jima had the first pre-*D*-day bombardment with proximity-fused bombs in February 1945 from airplanes based upon Saipan. The antiaircraft fire after such a saturation bombing was unusually light. *VT*-fused bombs were most effective against antiaircraft personnel and demoralized the gun crews. In April 1945, the 15th Air Force from *B-24*'s at 25,000 feet dropped *VT*-fused bombs on flak positions in Northern Italy. All enemy batteries ceased firing, and the main body of the air group followed through the corridor unmolested. There was no antiaircraft fire for $2^1/_2$ hours. The 9th, 12th, and 15th Air Forces used *VT*-fused incendiary bombs with devastating effect.

OFFICIAL TESTIMONIALS

Secretary of the Navy James Forrestal stated that the proximity fuse protected our surface ships and greatly reduced the cost in both men and ships of the Pacific war. General George Patton said, "The new shell with the funny fuse is devastating. The other night we caught a German battalion which was trying to get across the Saar river with a battalion concentration and killed by actual count 702. I think when all Armies get this shell we shall have to devise some new method of warfare. I am glad that you all thought of it first. . ."

VT FUSE CONSTRUCTION

The field of sensitivity of these *VT* or radio proximity fuses was designed to coincide as closely as possible with the burst pattern of the shell, in order that maximum effectiveness should be obtained. The amplifier is peaked at the Doppler frequency to reduce noise. Five safety devices are included for protection of our personnel.

In the proximity fuse a continuous-wave signal is transmitted and detection of the target is effected by the frequency shift of the reflected signal, a shift caused by the relative motion of the fuse and the object being detected.

As projectile and target are in relative motion, the proximity fuse can be considered as stationary, with the target approaching it at their relative velocity, v. The target then will intercept v/λ extra waves each second and, therefore, will receive a signal of apparent frequency

$$f_a = f_0 + v/\lambda$$

or, since

$$\lambda = c/f$$
$$f_a = f_0(1 + v/c)$$

To find the apparent frequency of the reflected signal finally received at the fuse, consider the target as stationary and the fuse as in motion. The reflected signal finally received at the fuse, therefore, will have a frequency

$$f_r = f_a(1 + v/c)$$

or

$$f_r = f_0(1 + 2v/c)$$

The transmitting antenna is also the receiving antenna, and the transmitting oscillator doubles as an amplifier and autodyne detector. The beat note, or difference between the local oscillator frequency and the received frequency, will be $f = 2f_0(v/c)$. The radio-frequency components of the combined signals are by-passed to ground, and the Δf then is amplified. Selective filter and feed-back circuits in the amplifier peak it at the Doppler frequency and adapt its sensitivity to its purpose.

Essentially, therefore, the *VT* or radio proximity fuse consists of a very compact oscillator which radiates a continuous signal to the sides of the projectile in a pattern approximating that of the shell burst; and this signal is reflected from any body in its field. The target need not even be a good conductor, as the induced current responsible for reflection can be a displacement current. Any discontinuity of conductivity, dielectric constant, or permeability can cause reflection. The reflected signal is picked up by the transmitting antenna, and interference between this reflected signal and the original signal gives a beat note. This signal, appearing across the load resistor in the plate circuit of the oscillator, which doubles as an autodyne detector, is filtered and amplified. The amplified signal then is applied to the grid of a miniature thyratron, which fires upon application of a strong enough signal, thus discharging a capacitor through the explosive squib. The squib sets off the auxiliary detonator, and that in turn sets off the high explosive charge. The whole fuse, consisting of antenna, oscillator, amplifier, thyratron, and firing capacitor is potted with a microcrystalline wax for moisture protection and for mechanical support.

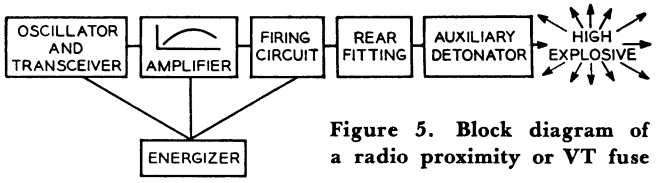


Figure 5. Block diagram of a radio proximity or VT fuse

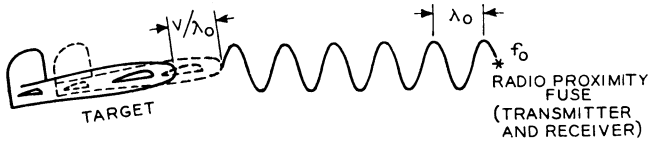
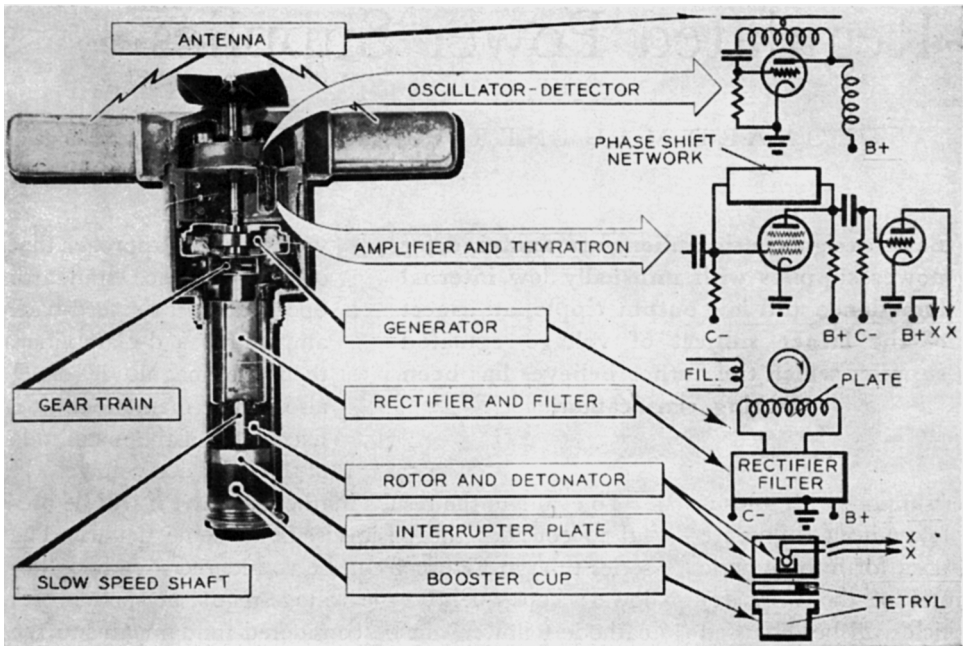


Figure 6. Doppler effect for moving transmitter

$f_a = f_0 + v/\lambda$
f_0 = frequency at origin (fuse)
f_a = apparent frequency at target
V = relative velocity of target and fuse
λ = original wave length of signal
C = velocity of light

THE ENERGIZER

The energizer, or battery, used in conjunction with the radio proximity fuse was originally a dry battery, and the voltages were applied to the fuse at setback or firing of the gun by inertia switches, which consisted of a tight coil of soft wire with a weighted end that sagged into permanent contact with a metal cup at setback. The shelf-life of these dry cells was limited to about six months, and the present type of battery consequently was evolved with an acid-containing ampule which breaks at setback, thus activating the battery. One of the great problems in designing this energizer was the elimination of random potential fluctuations, otherwise known as noise, during the flight of the projectile.



National Bureau of Standards photo

Figure 7. A cutaway view of the generator-powered bomb use with a schematic circuit diagram of the primary subassemblies

For bomb fuses a small wind-driven propeller was used to drive a generator which supplied the necessary electric power for the fuse. This finally was made into a more compact and more vibration-free turbogenerator rotating at 50,000 rpm.

SAFETY DEVICES

Five precautions were built into the complete assembly of the proximity fuse in order to avoid danger to firing personnel and friendly troops. These were:

1. The energizer is not operative until setback breaks the acid-containing ampule, and spin from the rifling in the gun barrel is required to distribute this electrolyte through the battery.

2. A mercury switch short-circuits the squib until the unit is spun at high rate. (In normal operation a charged capacitor is discharged through the squib to detonate the shell.)

3. A mechanical spin switch is incorporated to short-circuit this capacitor unless the unit is spinning. This gives protection until the unit is fired from the gun. When the rate of spin falls below a preset value after a charge has built up on the capacitor during flight, this switch discharges it through the squib, thus insuring self-destruction of the unit.

4. An out-of-line powder train is incorporated between the squib and the charge in the auxiliary detonator. This powder train is aligned by the spinning action.

5. A time delay is incorporated in the charging circuit of the capacitor which fires the squib to prevent the shell from detonating until it is well away from the gun and from firing personnel and friendly troops.

The first four precautions, which function by preventing activation of the energizer, by short-circuiting the explosive squib, by not allowing the firing capacitor to build up its charge, and by preventing the squib from firing the auxiliary detonator, keep the projectiles high-explosive charge from going off until it actually is fired from a gun. Even dropping the projectile and releasing the electrolyte cannot actuate the fuse. The fifth precaution prevents muzzle bursts which could destroy gun and crew, or prematures which might scatter fragments among an army's own troops when the projectiles are fired over their heads at the enemy.

On the bomb fuses an auxiliary propeller and gear train could be clipped to the fuse which would release the fuse propeller after a predetermined amount of air travel. This allowed the fused bombs to be dropped safely through deep formations of bombers.

Generator-powered fuses also were used on rockets fired from airplanes, thus providing them with the equivalent of heavy caliber guns.

IMPORTANCE OF THE PROXIMITY FUSE IN WORLD WAR II

Admittedly, the atomic bomb is the world's outstanding weapon, highlighting the need for the international rule of law and order; but radar and the proximity fuse had as important a role in World War II as any other single project. Although the Manhattan Project, the release of atomic energy, will have a much greater effect on the history of mankind and on the terms of peace, nevertheless, Project *A*, proximity field fuses for bombs and shells, affected more greatly the outcome of World War II.

These fuses in themselves have served to increase the effectiveness of antiaircraft fire about five times. Early in the war, it took about 1,000 shells to bring down an airplane; with mechanical time fuses and radar fire control about 500; with *VT* fuses about 85–100. Proximity fuses helped to save London from the buzz bomb, helped to turn the tide at the Battle of the Bulge, helped to oust the Japanese from his foxhole, helped to make the "kamikaze" impotent.

Howitzer bursts at tree-top height, or just above the ground, drove the stunned Germans from the forests of Bastogne. *VT*-fused antiaircraft fire, with the aid of automatic radar tracking, brought down more than 80 per cent of the robot bombs over England and most of the Japanese "kamikaze" airplanes over the Pacific. *VT*-fused rockets also were used effectively against aircraft and ground installations.