[redacted]

UNCLASSIFIED

Division 4, National Defense Research Committee
of the
Office of Scientific Research and Development

DECLASSIFIED
DOD DIR 5200.9

VT FUZES FOR ROCKETS AND BOMBS

Training Lectures

REVIEWED FOR CLASSIFICATION
JUL 11 1955
(Date) (Initials)

RECEIVED
16 NOV 1945
INFO. DIV.
TECH. COMD.
E. A.

NDRC Report No. A-334
OSRD Report No. 5326

This document contains information affecting the national defense of the United States within the meaning of the Espionage Act, U.S.C., 50; 30 and 32. Its transmission or the revelation of its contents in any manner to an unauthorized person is prohibited by law.

Copy No. 174

UNCLASSIFIED

[redacted]

[redacted]

Division 4, National Defense Research Committee
of the
Office of Scientific Research and Development

Mar 7 46

VT FUZES FOR ROCKETS AND BOMBS

Training Lectures

NDRC Report No. A-334
OSRD Report No. 5326

Approved for the National Bureau of Standards by

Harry Diamond, Chief
Ordnance Development Division

Lyman J. Briggs, Director
National Bureau of Standards

Approved for NDRC by

Alexander Ellett, Chief
Division 4
Ordnance Accessories

[redacted]

This report was edited and prepared for duplication by, and is distributed by:

Technical Reports Section
Office of the Vice Chairman, NDRC
Room 4724, Munitions Building
Washington 25, D.C.

Requests from Service personnel for additional copies should be addressed to:

War Department

War Department Liaison Officer
with NDRC
Headquarters, Army Service Forces
The Pentagon
Washington 25, D.C.

Navy Department

Research and Development
Division
Office of Research and
Inventions
Room 0150, Navy Department
Washington 25, D.C.

[redacted]

Preface

The work described in this volume is pertinent to the project designated by the War Department Liaison Officer as OD-27 and to the projects designated by the Navy Department Liaison Officer as NO-77B and NO-77R.

Initial distribution of copies of the report

Nos. 1 to 16 to Liaison Office, OSRD;

Nos. 17 to 23 to Office of the Executive Secretary, OSRD;

No. 24 to R. C. Tolman, Vice Chairman, NDRC;

No. 25 to A. Ellett, Chief, Division 4, NDRC;

No. 26 to L. J. Briggs, Member, Division 4, NDRC;

No. 27 to W. D. Coolidge, Member, Division 4, NDRC;

No. 28 to H. Diamond, Member, Division 4, NDRC;

No. 29 to H. L. Dryden, Member, Division 4, NDRC;

No. 30 to F. L. Hovde, Member, Division 4, NDRC;

Nos. 31 to 36 to Office of Field Service, OSRD (K. T. Compton);

No. 37 to Office of the Secretary of War (E. L. Bowles);

No. 38 to War Department Special Staff (Director, New Developments Division);

No. 39 to War Department Liaison Officer with NDRC;

No. 40 to Aberdeen Proving Ground;

No. 41 to AAF Board, Orlando, Fla.;

No. 42 to AAF Proving Ground Command, Eglin Field, Fla.;

No. 43 to Army Air Forces (Brig. Gen. R. C. Coupland);

No. 44 to Director, Camp Evans Signal Laboratory;

Nos. 45 to 47 to Ordnance Department (Col. C. H. M. Roberts, Lt. Col. H. S. Morton, Col. I. A. Luke);

No. 48 to Research and Development Division, Office of Research and Inventions, Navy Department;

Nos. 49 to 52 to Bureau of Ordnance (Comdr. J. A. E. Hindman);

Nos. 53 to 152 to Army Air Forces (Col. J. M. Gruitch).

[redacted]

[redacted]

CONTENTS

LECTURE

[redacted]

[redacted]

FOREWORD

The lectures contained in this report were given by National Bureau of Standards personnel to Army and Navy personnel during a training program on the theory and application of VT fuzes for rockets and bombs (January 16 to 25, 1945). The text as presented is a revision of transcriptions obtained from recordings of the original lectures. The recordings of the questions asked during each lecture were very poor; however, attempts have been made to answer the questions in the revised text.

The class was introduced to the training course by

Brig. Gen. R. C. Coupland, Chief Air Ordnance Officer, AAF
Lyman J. Briggs, Director, National Bureau of Standards
Alexander Ellett, Chief, Division 4, NDRC
Col. C. H. M. Roberts, Research and Development Service, OD

The program was conducted by the following officers of the Ordnance Overseas Maintenance Modifications Detachment:

Maj. N. S. Butz
First Lt. M. W. Carroll
Second Lt. C. E. White
Second Lt. D. S. Hutton

The following is a list of Army and Navy personnel who attended the training program:

Army

Col. P. N. Gillon	
Lt. Col. R. G. Bennett	U.S. Strategic Air Forces
Lt. Col. A. C. Frampton	Headquarters, Eighth Air Force
Maj. P. E. Chappell	Research and Development Division; Headquarters, Army Service Forces
Maj. J. C. Crumbley, Jr.	Air Technical Service Command, Kelly Field
Maj. B. Taylor, Jr.	First Air Force
Maj. W. G. Leonard	Tenth Air Force
Maj. N. S. Butz	Ordnance Overseas Maintenance Modifications Detachment
Capt. L. F. Lawrence	
Capt. R. J. Cross	
Capt. W. G. Geselbracht	
Capt. A. S. Ordwell	2018th Ordnance Maintenance Company
Capt. R. J. Dullard	Headquarters, Ninth Air Force
Capt. D. E. Stage	13th Ordnance Bomb Disposal Squadron
Capt. C. L. Burton	Headquarters, Fifth Air Force
Capt. J. D. Brown	TS ORD-1, Wright Field

[redacted]

[redacted]

Army [concluded]

First Lt. F. J. Purtell	904th AAF Base
First Lt. W. D. Cannon	Sq. P. (Facilities) 903rd AAF
First Lt. L. B. Orange	Headquarters Twelfth Air Force
First Lt. G. B. Gnam	610th AAF Base, Unit K
First Lt. C. M. Ball	344th Fighter Squadron
First Lt. E. F. Washburn	First Tactical Air Force
First Lt. M. W. Braasch	1916th Ordnance Am. Co.
First Lt. J. E. Houk	Ordnance Overseas Maintenance Modifications Detachment
First Lt. M. W. Carroll	
Second Lt. C. E. White	
Second Lt. D. J. Hutton	
Second Lt. J. D. Parry	28th Fighter Squadron
Second Lt. A. P. Diehl	Special Projects Branch
T/Sgt. L. C. Bratt	Eighth Air Force, Second Division
T/Sgt. G. E. Brookwell	Tenth Air Force
T/Sgt. V. C. Scarpone	Ord. Sec. 610th AAF Base, Unit K
T/Sgt. R. A. Emmons	Ord. Sec. 610th AAF Base, Unit K
T/Sgt. E. J. Malan	358th Fighter Group
T/Sgt. R. L. Carter	1659th Ord. S and M Co. (Aun)
T/Sgt. F. Moore	500th Bomber Squadron
T/Sgt. H. D. McQueen	78th Ord. Bomb Dip. Squadron
T/Sgt. C. P. McCabe	82nd Fighter Group
S/Sgt. J. H. Simpson	97th Bomber Group
S/Sgt. C. R. Hartman	1659th Ord. S and M Co. (Aun)
S/Sgt. P. A. Blake	404th Bomber Squadron
S/Sgt. A. P. Roberton	Ord. Sec. 610th AAF Base, Unit K
S/Sgt. H. J. Gabrick	89th Fighter Squadron, 80th Fighter Group
S/Sgt. J. J. Barrett	490th Bomber Squadron
S/Sgt. H. W. Modglin	2070th Ordnance Training Company
Sgt. G. G. Brown	1105th AAF Base Unit
Sgt. C. J. Murnane	1105th AAF Base Unit
Sgt. J. R. Lewis	Eighth Air Force, First Division
Sgt. W. A. Sargent	1962nd Ord. Dept. Co. (Aun)
Sgt. L. A. Green	324th Fighter Group
Sgt. E. F. McClure	1431th Ord. Med. Auto
Sgt. B. D. Mumma	1427th Maintenance Plat (Aun)
Sgt. M. Dvorkin	2109th Ordnance Ammunition Bn.
T/4 S. G. Mossey	2003rd Ord. Mat. Co. AF
T/5 S. S. Badell	1832nd Ord. S and M Co. (Aun)
Cpl. R. E. Miller	1105th AAF Base Unit
Pfc. W. J. Tilliets	Ord. Sec. 610th AAF Base, Unit K

Navy

Lt. S. W. Rideout
Lt. (jg) E. C. Cole
Lt. (jg) P. A. Seip
Lt. (jg) J. G. McKee
Ens. F. L. Granger
Ens. R. D. Smith
Ens. C. W. Owens
Ens. G. A. Stumpf

[redacted]

[redacted]

I. LECTURE NO. 1

BASIC PRINCIPLES OF OPERATION OF THE VT FUZES

by R. D. Huntoon
January 19, 1945

1. Introductory remarks

This lecture will be concerned with the basic operating principles of VT fuzes and will include a general discussion of how the engineering principles are translated into a working device to solve a definite tactical problem.

The way we plan to handle the course is to have first, a general discussion of operating principles with a quick survey to show you how VT fuzes work and what they will do, and after that other lectures in somewhat more detail giving other pertinent information. In conjunction with these lectures there will be a series of classes. You have been divided into three separate groups. In the mornings, there will be lectures attended by all, and in the afternoons the smaller groups will visit special rooms prepared for demonstrations of actual operating equipment, or for specific small-group discussions of problems of primary interest to you.

You may have gathered the impression from introductory remarks to the course made yesterday, and from the size of the group that has been called together, as well as from the stress that has been put upon the whole program, that a VT fuze is a complicated device requiring that you spend a good deal of time here in order to understand it. I am sure you are going to be surprised when you find out how simple the working principles really are. You will find only a simple radio circuit (radar if you care to call it that) which operates on a simple but quite different principle. That principle, and the engineering required to make it useful as a working fuze, is to be the basis for the discussion in this first lecture.

You may rightly ask the question: if the device is so simple, why has it been so long in development? I can answer by saying that it is equally simple to state that the way to stop a dog fight is to separate the dogs. However, when you come to the actual separation, the difficulties arise. The situation is similar here. The engineering difficulties are problems

[redacted]

that have arisen in the laboratory and in the factory and would be of little interest here. We have met most of them. The device is now a working device and we wish to show you how it works and what you can do with it.

Before going into the details, a first quick description of a VT fuze will be helpful, so that you may see where the discussion is heading and be ready to watch for answers to certain special problems and certain interesting properties during the course of the discussion. In connection with various field experiments that have been run during the course of the fuze development, we have worked with quite a number of field engineers. I have been surprised to learn that a large majority of these engineers initially have the idea that a VT fuze is some mythical gadget that you can screw into the fuze well of a bomb, rocket, or shell, and thereby endow that projectile with a sort of soap-bubble surrounding it. It is their idea that any obstacle crossing the boundary of the bubble initiates the detonation. This conception has led to tests that have given very misleading answers — in some cases discouraging ones — regarding the operating efficiency and effectiveness of VT fuzes.

At the outset, let us get it clearly in mind that a VT fuze is a device quite different from this conception. It is a device which initiates an explosion when the projectile approaches a target. It is just as important that the projectile be moving toward the target as that the target be there. A VT fuze at rest in a field beside a target would not respond to its presence in the sense of causing a detonation. The motion toward the target is necessary for proper operation. Of course that is no restriction since projectiles that do not move toward the target are of little value anyway. This requirement that the fuze must move toward its target is in reality a considerable advantage since it allows projectiles fuzed with VT fuzes to get reasonably close to one another without causing mutual interaction.

When you make a device that is intended to notice and respond to objects in its surroundings, it by definition is going to notice objects in its surroundings. When considerable numbers of projectiles are involved, as in a salvo of rockets or a train of bombs, the projectiles are in the vicinity of one another. Fortunately, in general, they are moving toward the same target and with approximately equal velocity. This means that the motion of separation between projectiles is usually quite small and thus one does not form an effective target for another.

[redacted]

However, if for some reason one of the projectiles explodes in the vicinity of another, that explosion suddenly removes a projectile that was originally there. At the same time, it sets up a huge flaming mass of gas, an acoustic shock wave, and a series of flying fragments. Any one or a combination of these effects may serve to detonate a neighboring projectile carrying a VT fuze. The effectiveness of the explosion as a target for a neighboring VT fuze thus sets certain limits on the safe spacing between the projectiles. The spacing is small for small projectiles and gets progressively larger for the larger ones. You will be told in some detail the limiting spaces that can be used with various sizes of projectiles.

Again I wish to emphasize that you should watch carefully during the explanation of fuze action to see how it comes about that motion toward the target, as well as the presence of the target, is essential for fuze operation.

2. The problem

Suppose now we get down to the basic problem and state in detail what we set out to achieve in the design of the device. We wanted to do two things:

1. We wanted to burst a projectile in the air as it approached the ground at a height of approximately 50 ft.
2. We wanted to cause a projectile to burst upon passing an airborne target so that near misses could become effective shots.

Suppose you were considering the problem of causing a bomb to burst at an altitude of approximately 50 ft; I think you can immediately sense the tremendous difficulty of attempting to use a time fuze for such a device. You would have to know the altitude of the airplane within approximately 10 ft and you would have to have a sufficiently accurate time fuze so that the bomb would burst within 10 ft of where you intended it to be. If you succeeded in achieving this, and if variations in time of fall of bombs were sufficiently small, you might get bursts at heights between 30 and 70 ft. The idea has been tried, but the difficulties, as would be expected, seriously limit its utility.

As you learned in the introductory remarks of the course, a considerable number of methods for doing the job have been investigated and the one

[redacted]

that appears to be the most satisfactory is the radar principle upon which present-day VT fuzes operate.

In case you wish to cause projectiles to burst in the vicinity of an airborne target, time fuzes can be used to more advantage than in the case of bombs against the ground. Nevertheless, accurate range measurements are necessary, and close control in adjustment of the time of burst are required. It turns out that the use of the VT-fuze principle is much more effective since the problem is reduced to one of getting the projectile to pass close to the target without requiring an exact knowledge of the time at which the projectile is in position to do the damage.

The name VT applied to these fuzes means variable time, and it is intended to call attention to the property of the fuzes that makes them automatically select the proper time of burst so that they are in a position to do more effective damage to the intended target. As you will see in the course of the discussion, the properties of the fuze needed to give the desired variable-time action are somewhat different for ground approach and for function upon approach to an airborne target. In this and following lectures, you will see why the difference arises and how the fuze design is altered for each application.

3. Required characteristics

You now have in mind the problem. Let us list briefly the characteristics the device must meet.

The device has to be small. Some of the engineers feel that those who use the fuzes would like to have us design one which could be painted on the side of the projectile. As a matter of fact, it was decided that a device which did not project more than 5 in. in front of the nose of a bomb would be acceptable. The restrictions on rocket fuzes are not so great but once the components have been engineered into the small space available, there was no reason to make it larger for the rockets than for the bombs. In order to avoid changes in bomb design, loading equipment, and so forth, it was necessary to build a fuze so that it would fit a standard fuze well and not use more than the allotted 5 in. in front of the projectile.

The device has to be rugged. That means it must stand normal shipping and handling. In this connection there is one point which you men as instructors should get across to the men in the field. They will learn shortly that the fuze is an electronic device containing vacuum tubes and they will be inclined to handle it very gingerly using extreme caution. While reasonable handling is of course desirable, the device is rugged and can, and should be, screwed into the fuze well with a large wrench as you saw in the moving pictures previous to this lecture. It has a rotating vane in the front which must not be bumped or bent, but otherwise if you do not externally damage the fuze, the shocks and bumps which you normally give it with reasonable handling will not damage its internal mechanism. Of course, it cannot be tossed around and dropped on the ground with impunity.

The fuze must be safe. During the course of the development, extreme emphasis has been placed on safety, and, as you will learn, unless the fuze is moving through the air, it does not have the energy developed to initiate the explosion (this does not hold for the T5 battery-powered rocket fuze which has other and different safety mechanisms to isolate the battery from the fuze mechanism until the projectile is well on its way). In that sense it is quite different from the usual contact fuze. Allow me to repeat, it is absolutely essential for the operation of a generator-powered VT fuze that it be moving rapidly through the air with sufficient speed to run the wind-driven propeller. In addition to this, it must move a given distance through the air before the electric circuits are completed and the interruption in the firing train is removed. The exact details of the safety mechanism will be demonstrated and explained during the training course.

The fuze must fit common projectiles. If possible, it would be desirable to design one fuze that could work on any of a group of projectiles having a common fuze well. The present design has the same threads and fits the same fuze well as the M-103 fuze. However, this does not mean that any VT fuze will work on any vehicle which normally uses an M-103 fuze.

There are two kinds of fuzes: bar and ring type. The ring-type fuze is shown in Fig. 1 and the bar-type is shown in Fig. 2. The ring-type fuze, as you will see from Fig. 1, is characterized by a ring surrounding the rotating vane. The bar-type fuze is characterized by two rods stuck out at the sides of the rotating vane. These names have been chosen because they do not give away the difference in the operating principle. You will find in the tactical bulletin with which you have been supplied that the fuzes have been designated by ring and bar type, and that no mention is made in the tactical manual of the fact that these are radar fuzes and that they work upon a radio-reflection principle. The ring-type fuze uses the projectile itself as a transmitting and receiving antenna. The bars of the bar-type fuze constitute the transmitting and receiving antenna, and were not put there to serve as handles for screwing the fuze into the bomb. As a matter of fact, they will probably break off if you attempt to use them in that manner. The bars are part of the fuze and carry the radio currents that make it function. You may wonder what this discussion has to do with the requirement that the fuze fit common projectiles. There is a very definite connection. The projectile itself becomes part of the VT fuze and as a result must be considered in connection with fuze operation. In the ring-type fuze, the relation between fuze and projectile is more intimate than in the bar-type. But in either case the projectile must be considered. This is a basic difference between VT fuzes and ordinary mechanical fuzes. For that reason there will be certain precautions in the manner of assembly which you must watch. These precautions are so simple they may easily be forgotten. Forgetting them will be costly but not dangerous, as you will see in the course of the discussion.

The fuze must be ballistically correct. In other words, its use on a projectile must not change the trajectory by an amount sufficient to require new bombing or firing tables. The ballistic effect of the fuzes as now designed has been shown by tests at the ordnance proving ground at Aberdeen to be less than the variations between projectiles without the fuzes. There is an effect but it is not large enough to concern us further.

The fuze must be reliable. We have made it as reliable as we know how and continually make improvements to increase its reliability. It does not have as yet the reliability of a mechanical fuze. At the present time you can expect 80% to 90% proper functions when the fuze is correctly used. That may sound like a considerable loss when you figure that by using the fuze you may lose the effectiveness of some 10% to 15% of the projectiles. However, the fuze was developed for certain specific purposes and when used for those purposes it increases the effectiveness of the projectile from 3 to 20 times. Under these conditions, the loss of 10% to 15% is more than counterbalanced by the increased effectiveness of the projectiles that

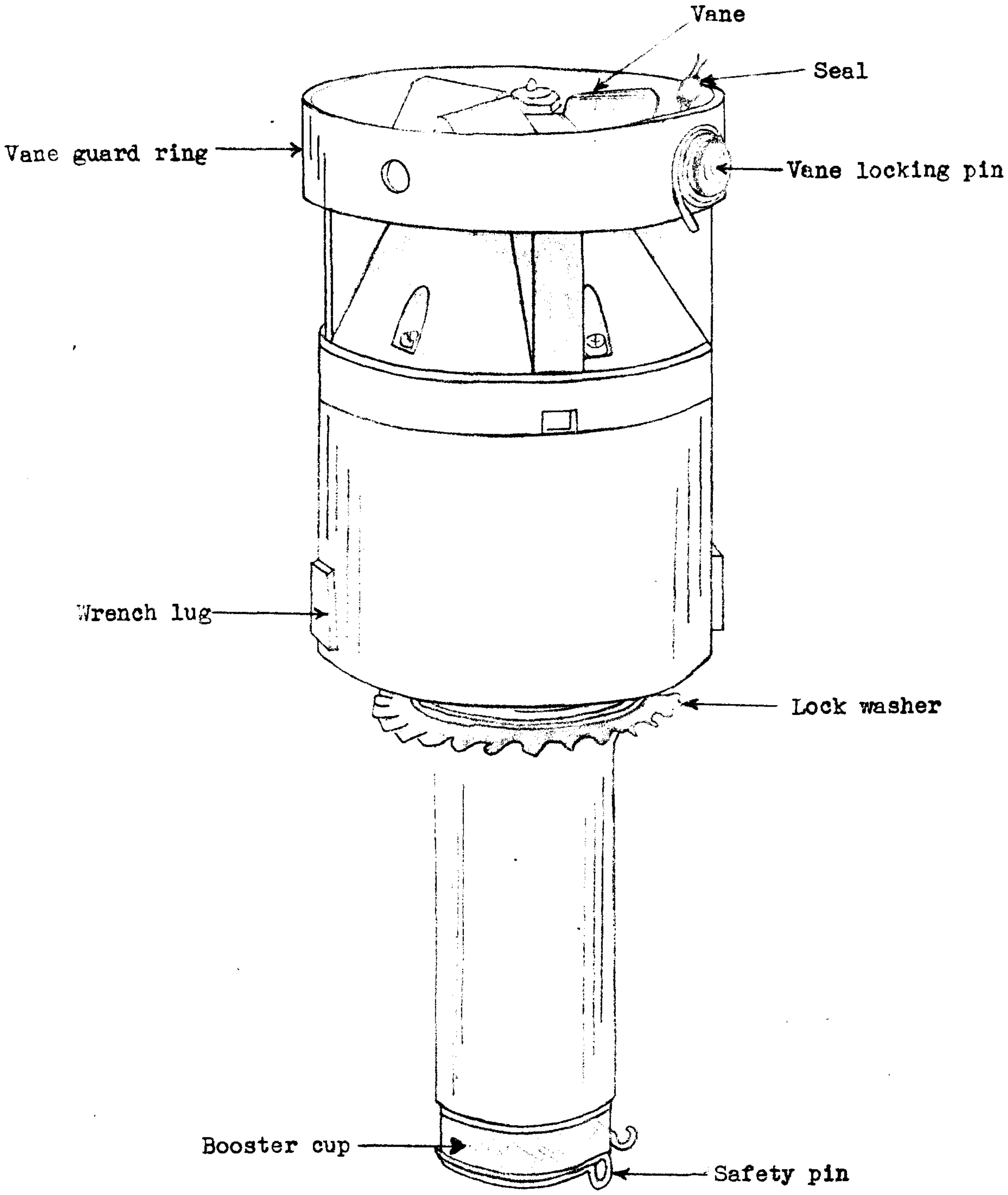


Fig. 1. Ring-type VT bomb fuze.

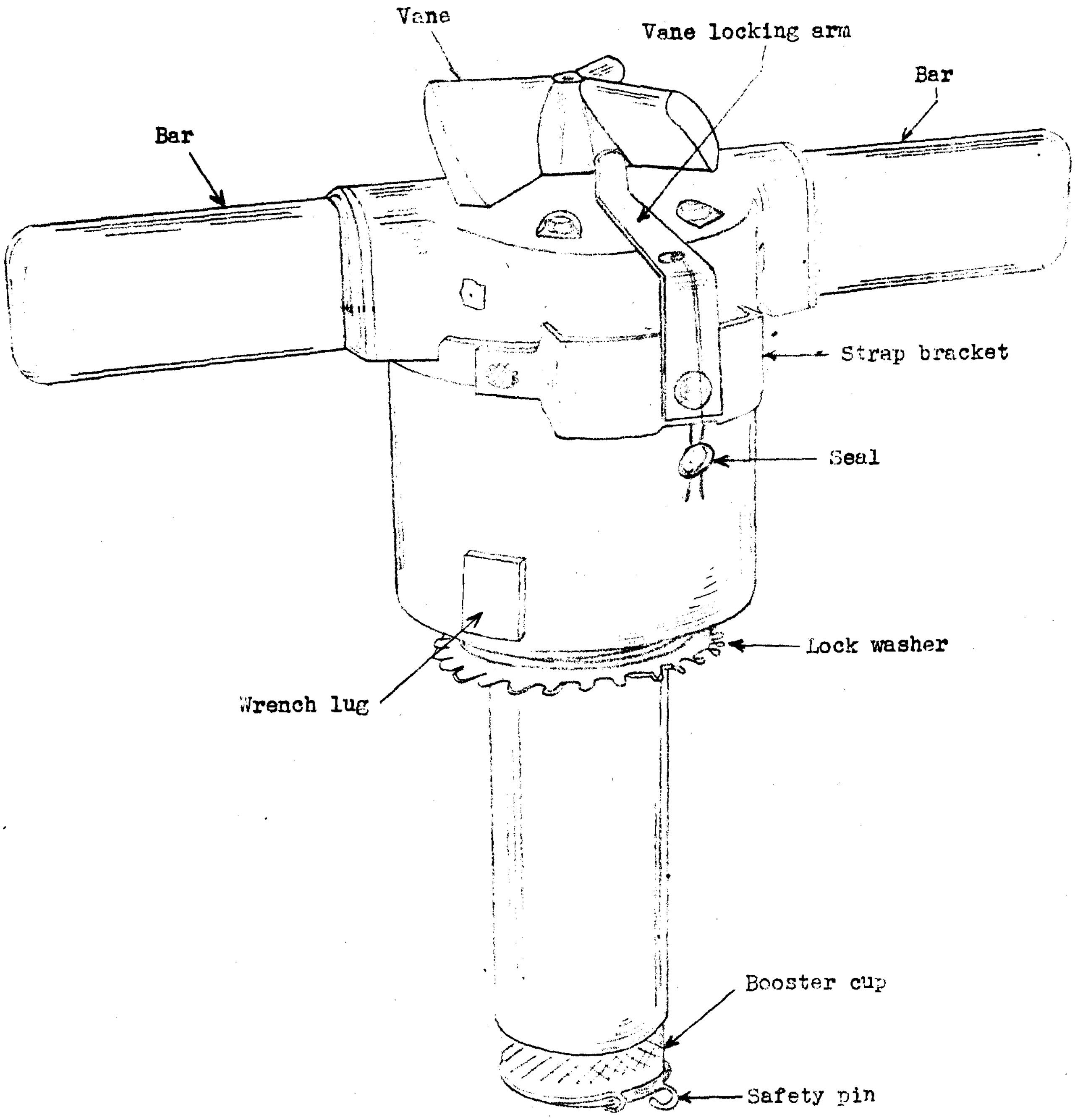


Fig. 2. Bar-type VT bomb fuze.

function properly. True, we do not like the loss any better than you do. During the development and manufacture every effort is being made to cut that loss. As the factories learn to make the device and learn how to avoid certain mistakes, the performance score increases. While we say, to be conservative, that you can expect 80% functioning, the proving-ground scores show that the trend is continually toward improvement and at the present time the scores hover between 80% and 90%.

The fuze must work under normal operating conditions. That means it must work in daylight and in dark and should work under most conditions where an airplane can be used. It will work under most conditions but there are some definite limitations. During the course of the discussion, these will be pointed out to you. We want to be sure that you get a clear picture of what the limitations are. You will notice from the schedule of lectures that lecture No. 4 is to be devoted to this discussion, so it need not be discussed further here.

The fuze must be simple to install. You have seen moving pictures of the installation procedure and not much more needs to be said about it. You screw it tightly in the bomb, tighten the fins, install the arming wire and the job is done.

The fuze must give proper burst characteristics. The requirements have already been outlined. The way it meets the requirements will be explained in a later lecture devoted to this subject.

Mass production of the fuze must be possible. It is being mass produced now, so that requirement has obviously been met.

To sum up the required characteristics, we are to design and build a fuze of the size you can hold in your hand, that is rugged, safe, fits common projectiles, does not alter the ballistics, works under usual operating conditions of aircraft, is simple to install, bursts in the right place, and is suitable for mass production. I think you can now begin to see that although the working principle may be quite simple, engineering difficulties are to be expected.

4. Working scheme

Let us turn our attention now to the actual electronic system used to do the job.

(a) Operating principle. -- You have been told that the device works on the radar principle. In fact, it is a small 4-tube radar set. However, it does not work on the usual radar principle. There are three basic radar principles:

1. The first method is to send out a pulse and measure the time until the echo returns. If the burst is to occur at 50 ft from the target, the echo time would be approximately 0.1 μsec. That is a very short time interval to measure with a device that can be built in the space available for a fuze.

2. The second method is the absolute altimeter method in which a wave is radiated whose frequency changes rapidly during the time the radiation goes to the target and returns. The transmitting frequency is changed and the difference in frequency between the transmitted and reflected signal is measured. That principle has been carefully considered and dismissed in favor of the third method now used.

3. The third method will now be described in more detail. Since the device is essentially a radio receiving and sending system, it must have a transmitting antenna, a receiving antenna, a transmitter, a receiver, and a power supply to actuate it. It must also have an electronic control device which examines the output of the receiver and responds to the proper signals in a manner that causes the detonation to occur in the proper place. In addition, there must be a system of safety devices so arranged that the fuze is armed when you are ready to have it armed and not until then. All of this must be built within the space limits of 5 in. mentioned previously. This rules out, for reasons that will not be discussed here, the use of complicated directive-antenna arrays. In these fuzes, the receiving antenna and the transmitting antenna are one and the same.

In the ring type, the body of the projectile serves as the antenna. In the bar type, the two bars are used. Aside from the antenna, all the elements are inside the fuze. Our problem now is to see how the radiation gets to the target, how it is reflected back, and how the reflected radiation causes the fuze to function. As already mentioned, the principle of operation is very simple, and to explain it, we will first make use of an analogy.

Imagine that you are riding in an automobile with the throttle set to give a certain fixed speed on a level roadway. If the car comes to a hill, the engine speed will be reduced on an upgrade and increased on a downgrade. This is due, of course, to the fact that going uphill places an additional load on the power system and going downhill removes some of it. I think you can well imagine that it would be quite possible to tell by watching the speedometer whether the car was going uphill or down, and even to count the number of hills and valleys encountered during the course of the ride. In fact, it should be quite possible to arrange a mechanical device that could count and record the hills and valleys. Suppose further that you knew the enemy had an ammunition dump located at the end of a roadway with five or six hills and valleys between you and it. It is conceivable that you might take an automobile loaded full of explosives and set it moving down the roadway with such a hill-and-valley counter installed in it. When the car had gone through the requisite number of changes in speed, indicating that it had traversed the required number of hills and valleys, the mechanism could be used to detonate the charge and thereby destroy the ammunition dump. Of course, there are probably much easier ways of solving this tactical problem, but this is intended to demonstrate a principle rather than to set forth a new means for destroying enemy ammunition dumps.

The VT fuze can now be tied into this analogy. While the projectile is moving freely through space, well away from any obstacles, the transmitter sends out a continuous undisturbed field of radiation, and if we measure with a voltmeter the output voltage of the transmitter it will be quite steady. When the fuze approaches an obstacle (the target) some of the outgoing radiation is reflected by the object back to the fuze. Electrically this reflected radiation has the same effect on the transmitter as the hills and the valleys had on the automobile in our analogy. As the fuze moves closer to the target, the reflected radiation interferes with the operation of the transmitter, making it sometimes harder and sometimes easier for it to send the outward radiation on its way. In short, the reflected radiation changes the load on the oscillator or transmitter just as the hill changes the load on the automobile engine.

We will find, if we examine things carefully, that the "electrical hills," arising as a result of the reflected radiation, change from uphill to downhill (from heavy load to light load) each time the distance from the fuze to the target is shortened by an amount equal to $\frac{1}{4}$ the wavelength of the radio wave. There is an additional feature, not found in the previous simple analogy, that we might very well have incorporated -- that is, as the fuze gets closer to the target, the heights and the depths of the electrical hills and valleys increase as the reflection from the approaching target gets larger and larger.

The voltmeter used to measure the transmitter output would thus exhibit a cyclic series of increases and decreases as the fuze approaches the target. These changes will become more pronounced as the distance from fuze to target decreases. To build an operating fuze it then becomes necessary to devise an electronic circuit that will respond to cyclic changes in transmitter output voltage. When they occur with appropriate rapidity and with sufficient magnitude, the control circuit should then initiate the explosion. While such a scheme seems very impracticable in the analogy of the automobile, it turns out to be very easy electrically and is used in the present designs of VT fuzes.

(b) Block diagram of a working system. -- In Fig. 3 a block diagram of a typical fuze system is shown. By reference to the diagram, it will be easy to see quite quickly how a working fuze is arranged and the manner of its operation.

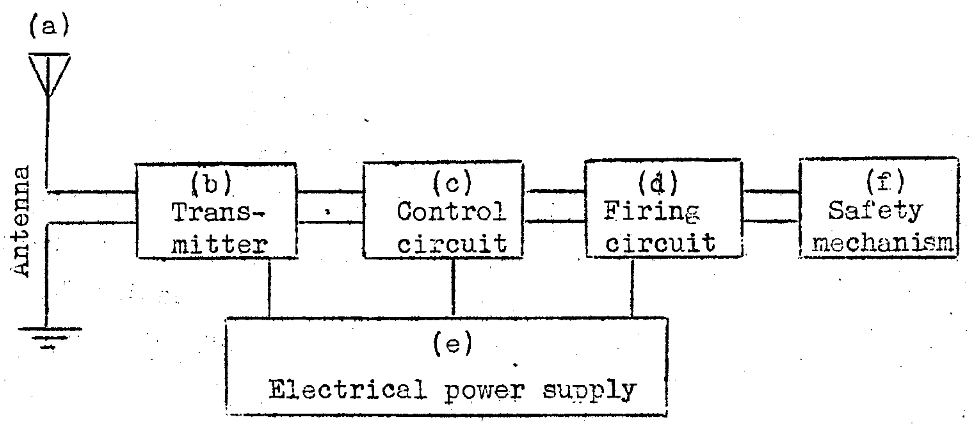


Fig. 3. Block diagram of a typical fuze.

Part (a) in Fig. 3 represents the radiating and receiving antenna system. As you have already heard, this may consist of one of two basic types. In either case, the same antenna is used twice: once for transmission of the outgoing radiation, once for reception of the reflected radiation. In ring-type fuzes (Fig. 1) the whole body of the projectile forms the antenna and it is excited electrically by means of the ring on the fuze, which forms a small part of the total antenna. In the bar-type fuze the two bars constitute the antenna and the body of the projectile plays only an in-

[redacted]

cidental part in that it itself is a reflector close to the antenna and in the region of strong fields. Thus the body of the projectile cannot be ignored and,because of its size, it determines to an extent the radiating properties of the small antenna formed by the bars.

Part (b) in the block diagram represents the load-sensitive transmitter we have already discussed in the analogy given in the previous subsection. As we have seen, the reflected radiation from the target changes the output voltage of this transmitter by interfering with the outgoing radiation and thus effectively changing the load upon it.

Coupled to the output of Part (b) is the control circuit, Part (c), which is essentially a shaped amplifier. It serves to amplify those variations in output voltage of Part (b) which are characteristic of interaction with a target and to suppress other noncharacteristic variations arising from noise or vibration. Thus the control circuit passes a firing impulse to Part (d) when the variations of transmitter output go through proper cyclic variations.

It is necessary to supply electrical energy to operate the electronic device. Part (e) represents this electrical power supply. In generator-type fuzes (T50, T51, T30, T82, T89, T90, and T91) the power is obtained from a wind-driven generator, associated rectifier, and filtering system.

In addition to the foregoing parts, which constitute the active electronic part of the fuze, there is a series of safety mechanisms so arranged that the fuze does not become a functioning device until it is well away from the firing point or release point, as the case may be. This safety mechanism is represented by Part (f) in Fig. 3.

The various items indicated in this block diagram will be explained in more detail here and in subsequent lectures.

5. Response to a reflector

(a) Doppler frequency. -- In the course of your experience to come with VT fuzes, you can expect to encounter individuals already familiar with some of their properties. Some of you may have had such an encounter already. You will no doubt either be told that or asked whether these VT fuzes work upon the Doppler-frequency principle. In the foregoing discussion, you have been told that the device works because of a change in load

[redacted]

on the transmitter and that this load goes through cyclic variations as the fuze approaches the target. From an engineering and designing point of view, this is the easiest way to undertake the operation and to make the necessary design calculations.

However, there is a fully equivalent way of thinking about the operation which leads to interpretation in terms of a Doppler frequency. The explanation is based on an electrical equivalent of the usual phenomena encountered when a moving source of sound -- for instance, a train whistle -- passes an observer. When the source of sound is approaching the observer, the frequency reaching his ear is slightly higher than that of the emitter. When the source recedes from the observer, the frequency of the sound he hears is less than that of the emitter. During the time the source passes by, the sound reaching the observer changes in pitch.

The same situation occurs with electrical radiation. When the fuze approaches the target, the frequency of the radiation that hits the target is slightly higher than that emitted by the fuze by virtue of the motion of the fuze toward the target. If you care to go through the analysis you will find that the frequency that strikes the reflector is higher than that leaving the fuze by an amount v/λ, where $\underline{v}$ is the velocity with which the projectile approaches the target and $\underline{\lambda}$ is the wavelength of the electrical wave. Likewise, as the fuze approaches the target, it receives a reflected radiation whose frequency is higher than that at the reflector by an amount v/λ again because of the motion of the fuze toward the target. The net effect of all this is that the reflected radiation comes back to the fuze with a frequency which differs from that of the fuze transmitter by a total amount $2\,v/\lambda$. This difference in frequency is called the Doppler frequency and if we look into the fuze circuits, we will find that the effect of mixing the returning radiation with the outgoing radiation is to give rise to a difference frequency of this magnitude. For example, suppose that the wavelength of radiation is 10 ft, corresponding roughly to a transmitter frequency of 100 megacycle/sec. Suppose also that the fuze approaches the target with a velocity of 1000 ft/sec. The apparent Doppler frequency ($2\,v/\lambda$) is immediately seen to be 200 cycle/sec. It will also be immediately evident that this Doppler frequency is proportional to the speed with which the fuze approaches the target.

[redacted]

As I just remarked, this way of thinking about the operation is fully equivalent to the variation-in-load method and should not be allowed to give rise to any heated discussions regarding which way the fuze operates. A careful study in some detail, which we do not have time to make here, will show that as the fuze moves toward the target, the load on the oscillator changes in such a manner that the output voltage of the transmitter goes from its minimum value to its maximum value and back again to its minimum value during the time the fuze moves a distance of $\frac{1}{2}$ wavelength toward the target or, in other words, it goes through two complete cyclic changes when the distance is shortened by a wavelength. This also leads to the value $2v/\lambda$ for the output frequency set up when the fuze approaches its target with a velocity $\underline{v}$.

(b) Meaning of sensitivity. — It will be necessary in further discussions of VT fuzes to use the term sensitivity. To avoid confusion and misunderstanding, this term needs quantitative definition.

Qualitatively, the sensitivity of the fuze means essentially what you would think it would mean. It is a measure of the responsiveness of the fuze to moving reflectors in its vicinity. For example, a high-sensitivity fuze will burst at a higher height above the ground than a low-sensitivity fuze, other things being equal. Also a high-sensitivity fuze can, in general, burst at a greater distance from an airborne target than a low-sensitivity fuze.

Quantitatively, the definition of sensitivity is related to the load changes produced by the encounter with the reflecting target and other amplifier properties of the control circuit following the radio-frequency part of the system (see Fig. 3). By sensitivity, we mean the change in radiation load on the oscillator required to actuate the firing mechanism. As will be seen later, the sensitivity of a fuze is different in different directions, since the antenna radiates more energy in certain preferred regions and receives signals better coming from those same regions. Also, the sensitivity depends upon the speed of approach to the target since the control circuit is arranged to have better response to certain cyclic variations characteristic of typical tactical situations than to other cyclic variations that may correspond to unwanted signals.

[redacted]

In the arguments in succeeding sections and in following lectures, it will be of assistance if you will bear in mind the qualitative and quantitative conceptions of sensitivity.

(c) Characteristics of operating signal. -- When the fuze approaches a reflector, we have already seen that the load on the oscillator varies at a cyclic rate to give what is called a Doppler frequency whose magnitude is $2v/\lambda$. Hereafter we will call this output from the load-sensitivity oscillator set up by an approach to a reflector, the operating signal. This operating signal has one other most important characteristic aside from its frequency; namely, its magnitude. When the fuze is a long way from the target, reflected radiation returning to it is of very low intensity and while a Doppler-frequency output is present, it is so small that it is masked by other noise in the circuit. When the fuze gets within a reasonable distance of its target, the reflected radiation is stronger and the resulting operating signal increases in magnitude. The main characteristics of the operating signal that are of interest are: (1) its frequency (Doppler frequency), and (2) its amplitude. We can make control circuits whose operation would depend primarily on the frequency of the operating signal or we can make them depend primarily on the amplitude of the operating signal, or we can make circuits that require certain components of both. Actually a combination of both is used. The control circuit (Sec. 8) is so arranged that the frequency of the operating signal must lie within certain limits. If it falls outside this region the sensitivity is greatly reduced and falls completely to zero for zero Doppler frequency.

(d) Importance of approach velocity. -- We are now in a position to see why I mentioned at the outset that it is just as important that the fuze be moving toward the target as it is to have a target there to set up the reflection. Advantage has been taken of the frequency characteristic of the operating signal to make the fuze so that it does not respond to very low Doppler frequencies. This means that it does not respond to the presence of other projectiles in the immediate vicinity moving with almost the same speed toward the same target (trains of bombs or rapid firing of rockets).

6. Radiating properties of bombs and fuzes

(a) Directivity patterns. -- We have already mentioned in Sec. 5 that the fuze does not radiate its energy equally in all directions. It therefore becomes necessary to specify the sensitivity of the fuze for different directions of approach. This we do by means of directivity patterns. If we specify a direction in terms of the angle θ with $\theta = 0^\circ$ off the nose of the bomb, we then can draw a curve where the ordinate is fuze sensitivity and the abscissa is the angle θ [Fig. 4(a)]. Such a curve is called a directivity pattern. It will be helpful to examine several typical directivity patterns (see Figs. 5, 6, and 7). These are shown both as the curve mentioned above and as perspective drawings which give a rough 3-dimensional picture of the distribution of sensitivity around a fuze. These patterns are very helpful in understanding the performance of the fuze provided they are properly interpreted. The curves of the directivity pattern represent fuze sensitivity in various directions but they do not represent burst surfaces. That is, they are not to be interpreted as outlines of the mythical soap bubble mentioned earlier. The sensitivity scale shown in the figures is purely relative for purposes of description. The actual burst surface is determined by the speed of approach as well as by this directivity pattern.

(b) Basic differences between ring-type and bar-type fuzes. -- It will be observed from Figs. 4, 5, 6, and 7 that there is a basic difference between the directivity pattern of the ring-type and the bar-type fuzes. This difference will be best understood by examination of the 3-dimensional directivity patterns shown in the figures. In general, it will be observed that the sensitivity is least off the nose and greatest near the side for ring-type fuzes and greatest off the nose and least off certain side positions for the bar-type fuzes.

There is yet another basic difference between ring- and bar-type fuzes. It is related to the way that performance of the fuze changes when it is attached to projectiles of different sizes. To go back to our analogy of the automobile, we may point out here that the size of the antenna plays much the same roll in gearing the transmitter to its surrounding space that the transmission in the automobile plays in gearing the motor to the roadway. Changing the antenna length is analogous to changing the gear reduction in the transmission (shifting gears) and hence changes the working load on the transmitter. Now it happens that the transmitter sensitivity to load changes depends upon how heavily or how lightly it is coupled to surrounding space, in other words, how heavy or how light the free-space radiation load that is impressed on the transmitter.

The ring-type fuze uses the body of the projectile for the antenna and hence has a different radiation load on each size of vehicle. This means that the over-all sensitivity can be expected to be different when the fuze is used on different bombs or rockets. It is for this reason, as well as for the properties of the directivity patterns, that it has been necessary to use two different fuze frequencies for the ring-type fuze. It is also the reason that one ring-type fuze is specified for certain projectile sizes and the other for the remainder.

The bar-type fuze has its own antenna and hence has a radiation load that is approximately the same on all projectiles. This is not exactly true because the presence of the projectile close to the bar antenna disturbs its performance and changes the directivity pattern somewhat as well as the radiation load.

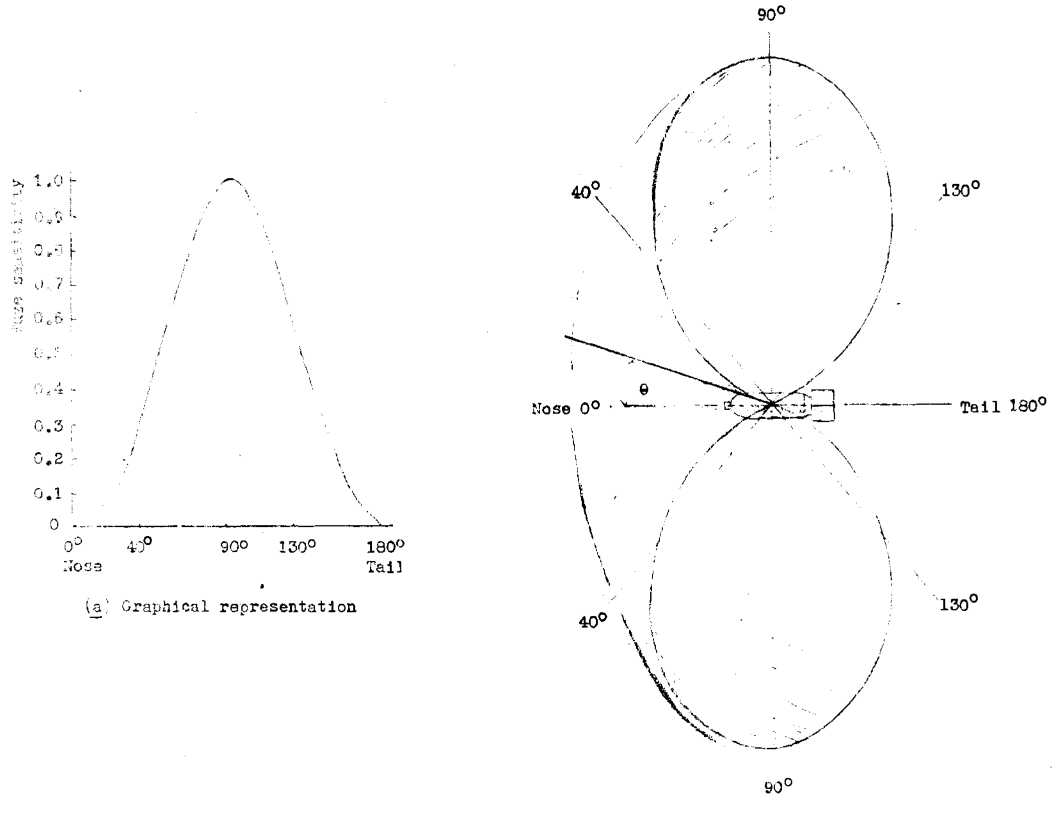
(c) Dependence of performance on projectile size. -- It can now be seen that with both types of fuzes, there will be a dependence of performance upon the size and shape of the projectile. With bar-type fuzes the changes will be less pronounced than with ring-type fuzes but must be considered in either case. It is for this reason that we say that the projectile itself becomes a part of the VT fuzes and that the whole combination of fuze and projectile must be considered as a working entity. For this reason it is important that the use of the VT fuze on a projectile for which its performance has not already been investigated be checked briefly by fuze engineers or at least by a field trial for operational use.

7. Interaction with targets

There are three typical applications of VT fuzes which require consideration since the mode of interaction with the target differs in each case. An understanding of this interaction will be helpful in promoting proper use in the field.

(a) Direct approach to a large flat surface. -- Consider as a first case the approach of a VT-fuzed bomb to a large flat surface. By large, we

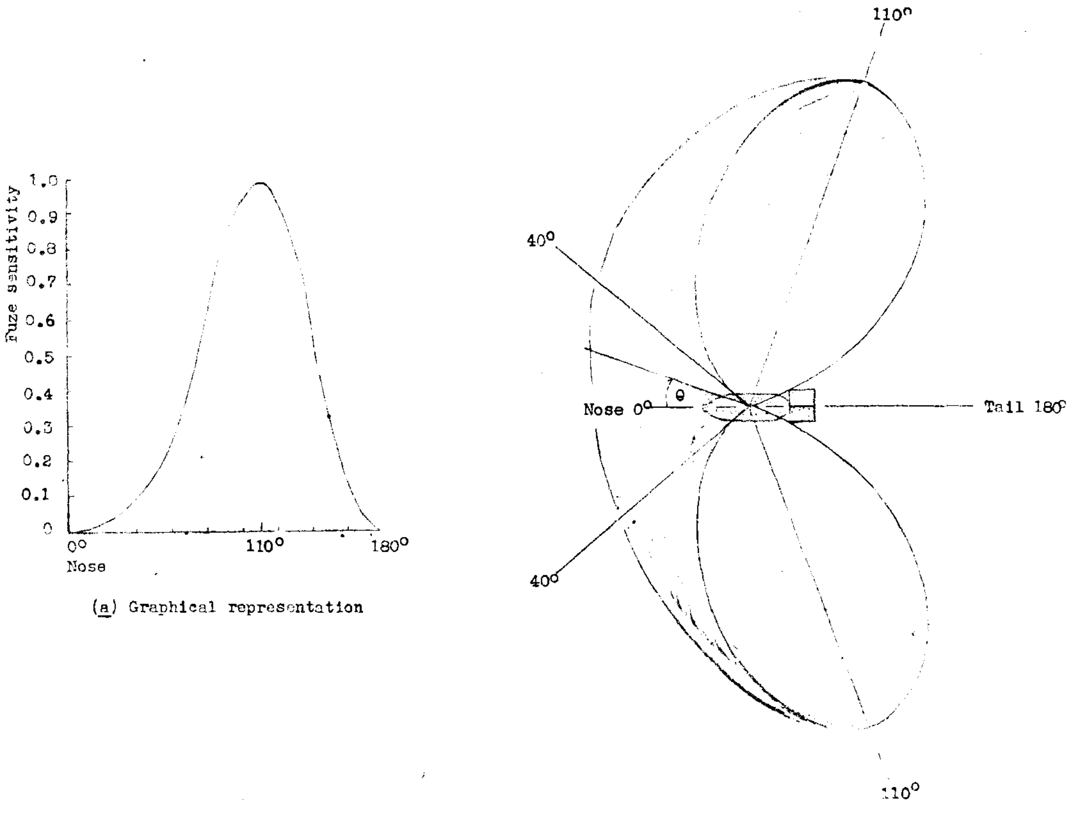
[redacted]



(a) Graphical representation

(b) Perspective drawing

Fig. 4. Directivity patterns of T50E1 ring-type fuze on M-30 bomb. Other fuzes of this type are: T50E4, T89, T90, T91, T92, T5, T6.



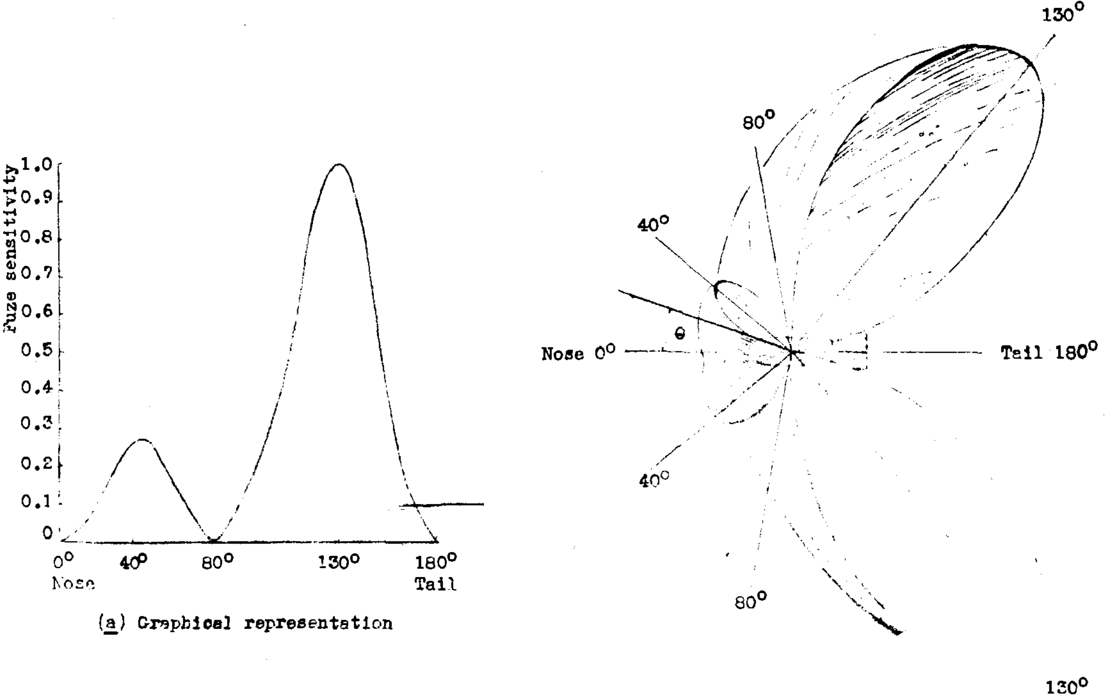
(a) Graphical representation

(b) Perspective drawing

Fig. 5. Directivity patterns of T[illegible] ring-type fuze on M-81 bomb. Other fuzes of this type are: T50E4, T89, T90, T91, T92, T5, T6

[redacted]

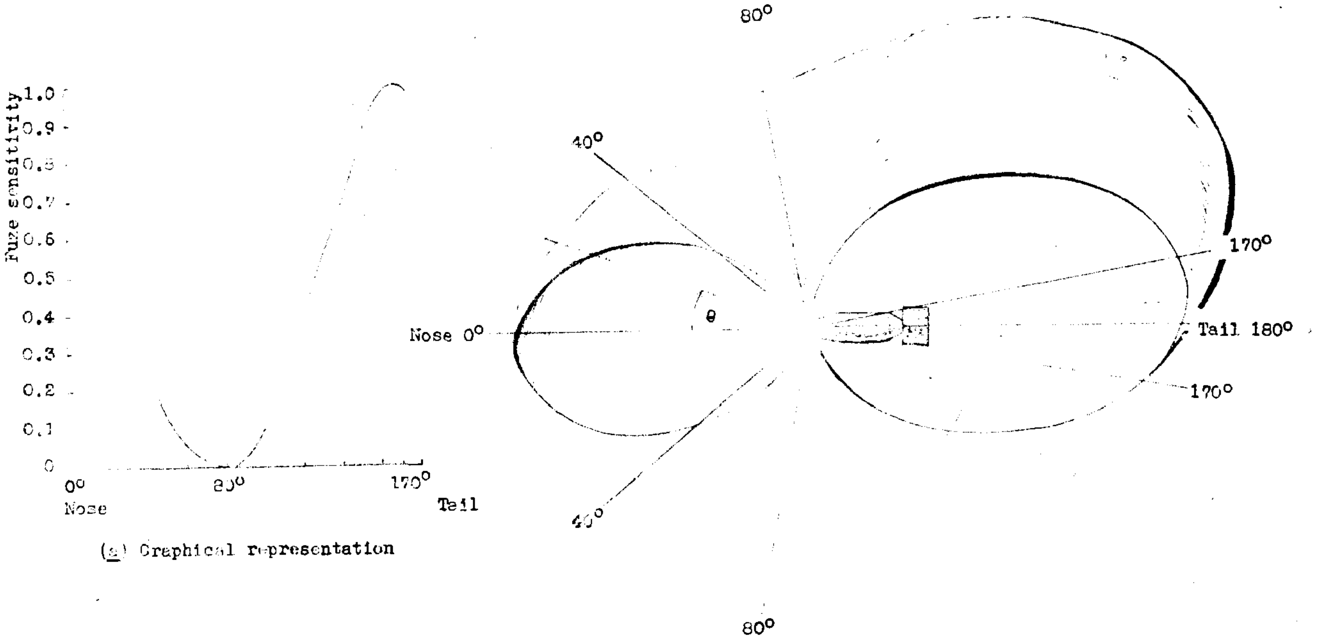
[redacted]



(a) Graphical representation

(b) Perspective drawing

Fig. 6. Directivity patterns of T50E4 ring-type fuze on M-64 bomb. Other fuzes of this type are: T50E1, T89, T90, T91, T92, T5, T6.



(a) Graphical representation

(b) Perspective drawing

Fig. 7. Directivity patterns of T51E1 bar-type fuze on M-64 bomb.

[redacted]

mean that the flat area has a diameter several times the height of burst. Irregularities small compared with the wavelength (such as puddles or foxholes) will have little effect and can be ignored.

The flat ground behaves much like a mirror in reflecting the radiation back to the fuze and it is helpful to think of the fuze seeing its image in the mirror. You all know from past experience that the line joining object and image is perpendicular to the surface of the mirror. The case is the same here; the reflection back to the bomb can be considered as coming from a point directly below it, that is, along a line from the bomb to the ground such that the line is perpendicular to the ground.

This line from the bomb perpendicular to the ground determines the direction that must be used if the sensitivity is to be obtained by reference to the directivity pattern. It is also the shortening of distance measured in this direction that determines the frequency of the operating signal. Each time the height shortens by half a wavelength the transmitter load change goes through one cycle of its variation. Figure 8 illustrates this ground approach.

Note that it is only the motion toward the surface that controls the Doppler frequency which is $2v/\lambda$[*]. This can be best explained further by means of a typical case.

Example: Consider a bomb dropped from 5000 ft by an airplane moving 300 ft/sec (~200 mi/hr). A bomb dropped from this height will behave almost like a freely falling body and we can treat it that way without any disturbing errors. When the bomb is 100 ft high it will have a vertical velocity v due to the fall of amount

$$v = 8\sqrt{h} = 8\sqrt{4900} = 560 \text{ ft/sec.}$$

---

[*] This is important for the case of a rocket fired from an airplane at a ground target. If the rocket is fired almost horizontally it has a high total speed but only a small velocity toward the ground. This means very low Doppler frequencies and erratic or poor fuze performance. In the language of the automobile analogy with hills and valleys, it is like driving the car around the hills to the munition dump instead of over them. Since the device was set to function by going over the hills, it is not surprising that it does not function if the hills are avoided. The same is true of the rocket. It should be fired so that it approaches the ground at an angle as steep as tactically allowable but always at angles less than 75° when measured from the vertical (see Fig. 8).

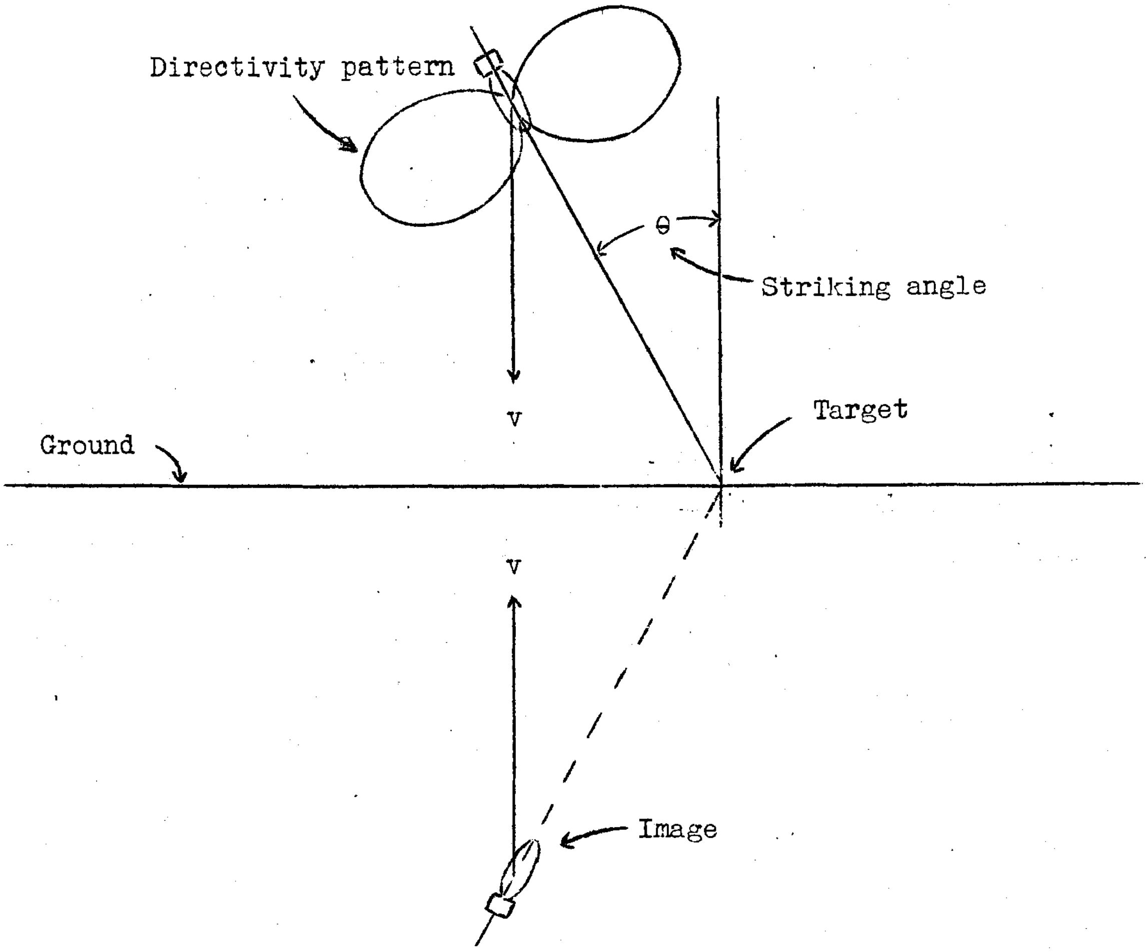


Fig. 8. Ground approach of ring-type fuze.

If the radio wavelength is 10 ft, the output signal frequency (Doppler) will be 112 cycle/sec. The striking angle θ measured from the vertical will be the angle whose tangent is 300/560,

$$\theta = \text{arc tan}\,\frac{300}{560} = 28^\circ.$$

To estimate fuze performance under these conditions we would need to know its sensitivity when the Doppler frequency is 112 cycle/sec and the direction to the target is 28° off the nose. During the last few hundred feet of fall the speed of the bomb does not change much and consequently we can say that the Doppler frequency and striking angle are constant during the time the operating signal is large enough to be of interest.

Since the frequency of the operating signal is essentially constant it is necessary to rely upon the change in amplitude for initiating fuze operation.

A careful analysis, based upon the fuze and image scheme already described, shows that the amplitude of the operating signal is inversely proportional to the height above the ground (except for very low heights where the signal is inversely proportional to the square of the height). This means that the amplitude of the operating signal doubles each time the distance to the ground is cut in half. It is this rapidly changing amplitude that is used to actuate the device. The electronic firing circuit is adjusted so that the fuze fires the detonator when the amplitude of the operating signal reaches a level characteristic of the reflection of average ground at a height of about 35 to 50 feet.

It is evident from what we have said previously that the height of burst is going to depend upon height of release, speed of release (striking angle), and the reflecting properties of the ground. All of this will be considered in detail in a later lecture. All we need to be sure to understand here is

1. During the last few hundred feet of fall the speed and striking angle are sensibly constant. Thus the Doppler frequency is constant.
2. The amplitude varies so that the amplitude of the operating signal grows in proportion as the height is decreased.
3. The dependence of height of burst on release conditions can be reduced greatly by proper fuze design.

One more point should be strongly stressed; that is, the Doppler frequency is determined by the motion <u>vertical</u> to the ground and not by the horizontal motion.

(<u>b</u>). <u>Passing approach to an airborne target</u>. -- When a VT fuze is fired to function upon an airplane the operating signal is quite different from that just discussed. In this case both Doppler frequency and amplitude vary. Figure 9 represents roughly the type of signal received.

It is the shortening of the line <u>r</u> from fuze to airplane that determines the frequency. Each time <u>r</u> shortens by half a wavelength the output signal goes through one cycle of its output. In Fig. 9, <u>p</u> represents the closest distance between the target and the trajectory of the projectile, and <u>v</u> the

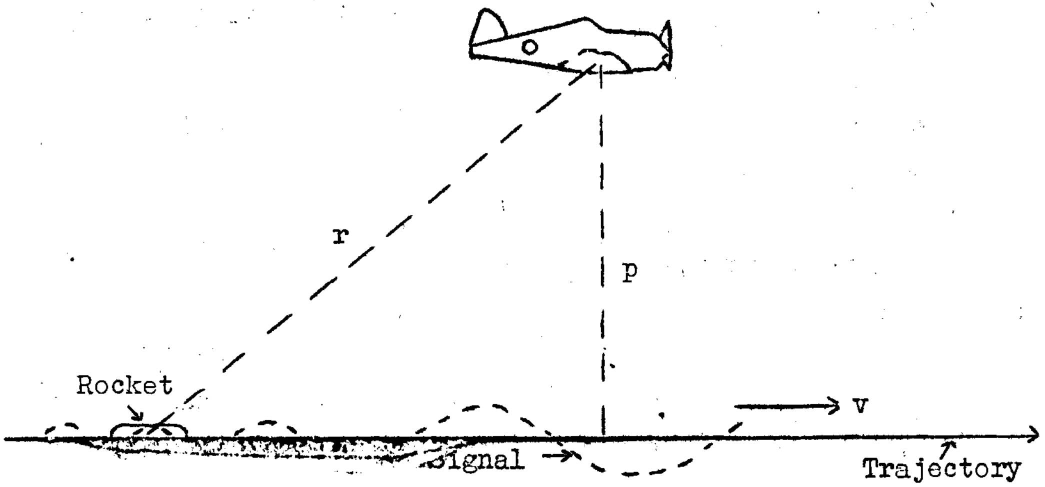


Fig. 9. Diagram of interaction of rocket and airplane.

overtaking velocity of the projectile (difference between plane speed and rocket speed). When r is much larger than p, the shortening of r is almost equal to v and the Doppler frequency is $2v/\lambda$ but the amplitude is small because the target is far away and because there is not much radiation in the direction of the target (a ring-type fuze is used). When r gets to be almost equal to p, the distance r from fuze to target is scarcely changing its length and the Doppler frequency is very low. At the same time the amplitude is large because the fuze is close to the target and the target is in the direction of strong radiation.

The operating signal upon approach to an airborne target is thus characterized by:

1. Decreasing frequency from a maximum of $2v/\lambda$ to zero.
2. Rising amplitude.

When the projectile passes beyond the target the sequence of events is reversed but this is of little interest.

In designing the fuze for this application, advantage is taken of both changing amplitude and frequency of the operating signal as well as of the directivity pattern to arrange the burst control so that close shots (small p) burst close beside the aircraft and poorer shots (larger p) burst a little before the projectile gets beside the aircraft, thus "leading" it to allow time for the fragments to travel from burst to target.

At the present time the fuzes will work for values of p (Fig. 9) up to about 60 ft. Please remember that when we say that the fuze will burst 60 ft from its target that this does not mean it will burst 60 ft away if it is going to come closer. The 60 ft refers to the distance p as drawn in Fig. 6 and a 60-ft radius of action for a fuze should be interpreted as meaning that if the fuze comes within 60 ft of the target it will burst in an effective position.

(c) Passing approach to an object on water or flat ground. -- This case is a combination of the previous two. It is more complicated than either and does not lend itself to simple interpretation. If a VT-fuzed projectile is fired horizontally over the ground so that it passes close to an object, it will function on passing the object much as if the object were airborne. When a bomb falls among trees or buildings both the ground-approach signal and the passing signal come into play. If the fuze passes close to a large structure on the way to the ground it will burst upon passing it. Otherwise it will function upon approach to ground.

If the target is one on the surface of the water, such as a ship or barge, the projectile should be aimed at it and fired to approach at a relatively steep angle. The water-approach signal will then cause air bursts and it will not be necessary to rely upon interaction with some part of the superstructure to give a burst over the target. Of course, if the target has masts, and so forth, the fuze can be expected to function on close approach to such structures in a manner similar to the case of the airborne target.

If it is desired to fire fuzes at such a target from level flight they must be fired from very level flight (± 2° or 3° from the horizon) and the trajectory must pass within a relatively short distance of the target, say 25 to 50 ft, if the fuze is to function upon it as a target. The most reliable attack is to aim at, or slightly past, the target with tactics such that the striking angle is 45° or less from the vertical.

The best available estimate now is that a built-up area will on the average raise the height of burst by an amount equal to half the average height of the structures.

In later lectures and conferences these problems will be discussed in more detail.

8. The control and firing circuit

The control and firing circuits are indicated schematically in the block diagram (Fig. 3). These will be described in some detail in later lectures. Now we will discuss briefly the working principle.

(a) Control circuit. — We have not mentioned quantitatively the amplitude of the operating signal developed by the load-sensitive oscillator. For typical applications, the operating-signal amplitude is usually in the region 0.01 to 0.1 volts and the frequency is in the region from 50 to 300 cycle/sec. More exact values are of interest only in particular situations. This much information is sufficient for an understanding of the part played by the control circuit.

The amplitude of the operating signal is too small to actuate the firing circuit directly. It must be amplified until its magnitude is 3 to 4 volts. If we make an amplifier that does not respond to very low frequencies (to allow trains of bombs, and so forth) and to frequencies above 300 cycle/sec (assorted noise disturbances) we can magnify the operating signal to usable size and leave the unwanted signals too small to actuate the firing mechanism.

The control circuit is just this sort of amplifier. Figure 10 is a curve which shows amplification as a function of frequency. Note that there is not much amplification below 50 cycle/sec or above 300 cycle/sec. In the region of interest the amplification is sufficient to actuate the firing device.

Although it has been indicated that the amplifier does not respond to unwanted signals, further clarification is needed. The types of signals that come out of the transmitter into the control circuit are quite varied. Those arising from loose or vibrating parts (fins, for example) are in some cases much larger than the desired operating signal and in such cases they actuate the firing circuit even though the amplifier gives them very little amplification.

The same is true of the operating signal that arises from the explosion of a nearby projectile if it is too close. The fact that it is not yet feasible to discriminate completely between wanted and unwanted signals leads to occasional operation on an unwanted signal. This appears operationally as an early function.

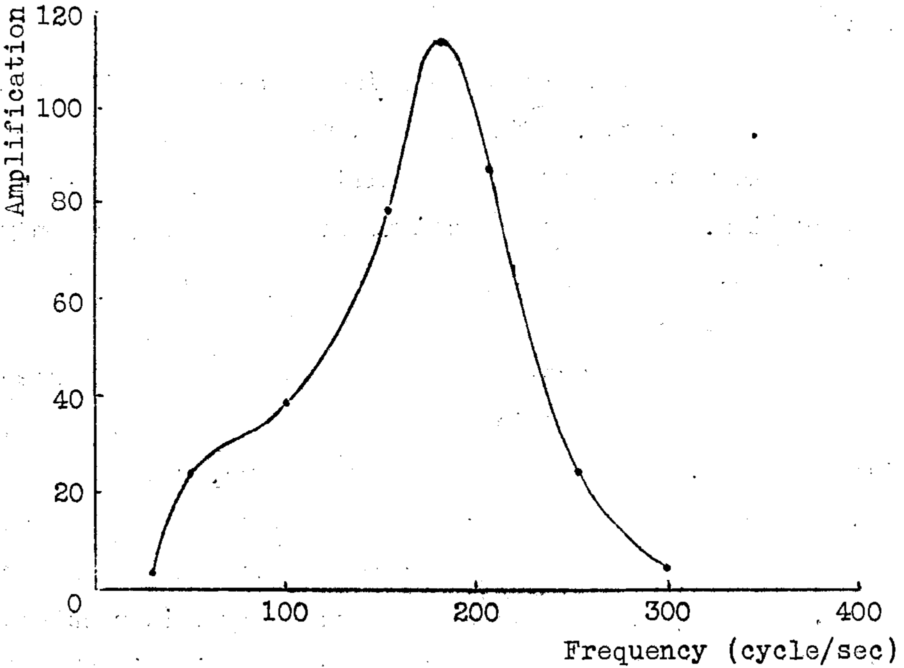


Fig. 10. Typical amplifier curve of ring-type fuze.

Some unwanted signals arise from vibrations of the fuze parts internally. These are being suppressed more effectively as the manufacturers learn to make the fuzes properly. Some arise from faulty assembly in the field. This must be prevented by care in assembly and inspection of fins and other component parts before assembly. It is most important that you learn about the necessary precautions during your training here. In spite of all precautions vibrations sometimes arise and lead to an early function. Continual improvements are being made to reduce this undesirable loss and at the present time with proper precautions not over 20% of such functions are to be expected. Current field tests indicate better than 85% proper functioning.

(b) Firing circuit. -- The firing circuit consists of an electronic discharge tube (thyratron) and an electric detonator (squib) arranged to burst the charge through an appropriate booster train. The electronic discharge tube is connected to the output of the control amplifier and responds by firing the squib whenever the output of the amplifier becomes larger than a certain critical value. This critical value is adjusted at the factory so that the over-all sensitivity of the fuze (quantitative concept) has the desired value within certain practical working limits.

9. Safety and arming

Tremendous emphasis has been placed upon incorporating adequate safety devices in these fuzes. Lectures, models, and demonstrations have been arranged so that you can become thoroughly familiar with the safety mechanisms and their operation. In this discussion, we are interested only in a very general description.

(a) Arming sequence. -- Arming of VT bomb fuzes is accomplished by the action of the wind stream on the arming vane of the fuzes. An unarmed VT bomb fuze has an out-of-line element in the explosive train and an open electric-detonator circuit. Rotation of the arming vane, reduced by a gear reduction system, serves to move the out-of-line explosive element into place and to connect the electric detonator into its associated electrical circuit. A fixed number of revolutions of the arming vane is required to complete arming; a further condition necessary for operation is that the arming vane be rotating at a high speed.

If the vane stops rotating after arming is completed, an undamaged fuze immediately becomes inoperative. (CAUTION: There is a remote possibility that this may not be true for duds that have been damaged as a result of impact.) A fuze whose arming mechanism has completed its cycle would be extremely dangerous if dropped from an airplane because it would become fully armed and live the moment the bomb entered the air stream.

(b) Safety provisions. -- To insure that fuzes issued for use have the arming mechanism in the safe position the vane is sealed at the factory to prevent rotation. An intact seal is a guarantee of safety. If the seal is broken, destroy the fuze.

Latest-model fuzes carry an additional safety feature in the form of a safety pin. This pin is inserted into the arming mechanism through an opening in the booster cup. It cannot be inserted unless the arming components are in the safe unarmed position. Each fuze comes supplied with this pin in place and the fuze cannot be inserted into the fuze well unless the pin is removed. A most important feature of the safety pin is that fuzes whose seals have been removed can have the arming mechanism checked for safety in the field. It also prevents willful sabotage of the sort that involves maliciously removing the seal from a fuze, advancing the arming, and replacing a new seal.

[redacted]

(c) Safe air travel (Fig. 11). — The requirement that the arming vane must turn a given number of revolutions before the fuze becomes armed means that the bomb must travel a certain distance through the air after the vane is released before the fuze will become operative. This distance is measured along the trajectory of the bomb and is called safe air travel, abbreviated SAT. Production variations of parts and assembly lead to variations of a few hundred feet in the SAT. Each lot of VT fuzes is tested on the AN-M30 (100-lb) bomb to evaluate the minimum safe air travel, abbreviated Min SAT, for that lot of fuzes. The Min SAT, that air travel before which no fuze will become armed, is marked on each fuze, container, and box.

(d) Vertical drop. — Conversion of safe air travel to equivalent vertical drop is of importance from two standpoints (refer to Fig. 11):

(i) Safety. Caution must be exercised that the vertical drop prior to arming is sufficient to provide adequate safety for both the carrying aircraft and any friendly aircraft at lower altitudes. After a VT bomb fuze is armed it will fire on the first target it approaches.

(ii) Performance. As mentioned, sufficient air travel should be provided to guarantee safety, but caution should also be observed to insure that excess SAT is not used. If the equivalent vertical drop exceeds the release altitude the bombs will impact with VT fuzes in the unarmed condition and the advantage of air burst will be lost.

[redacted]

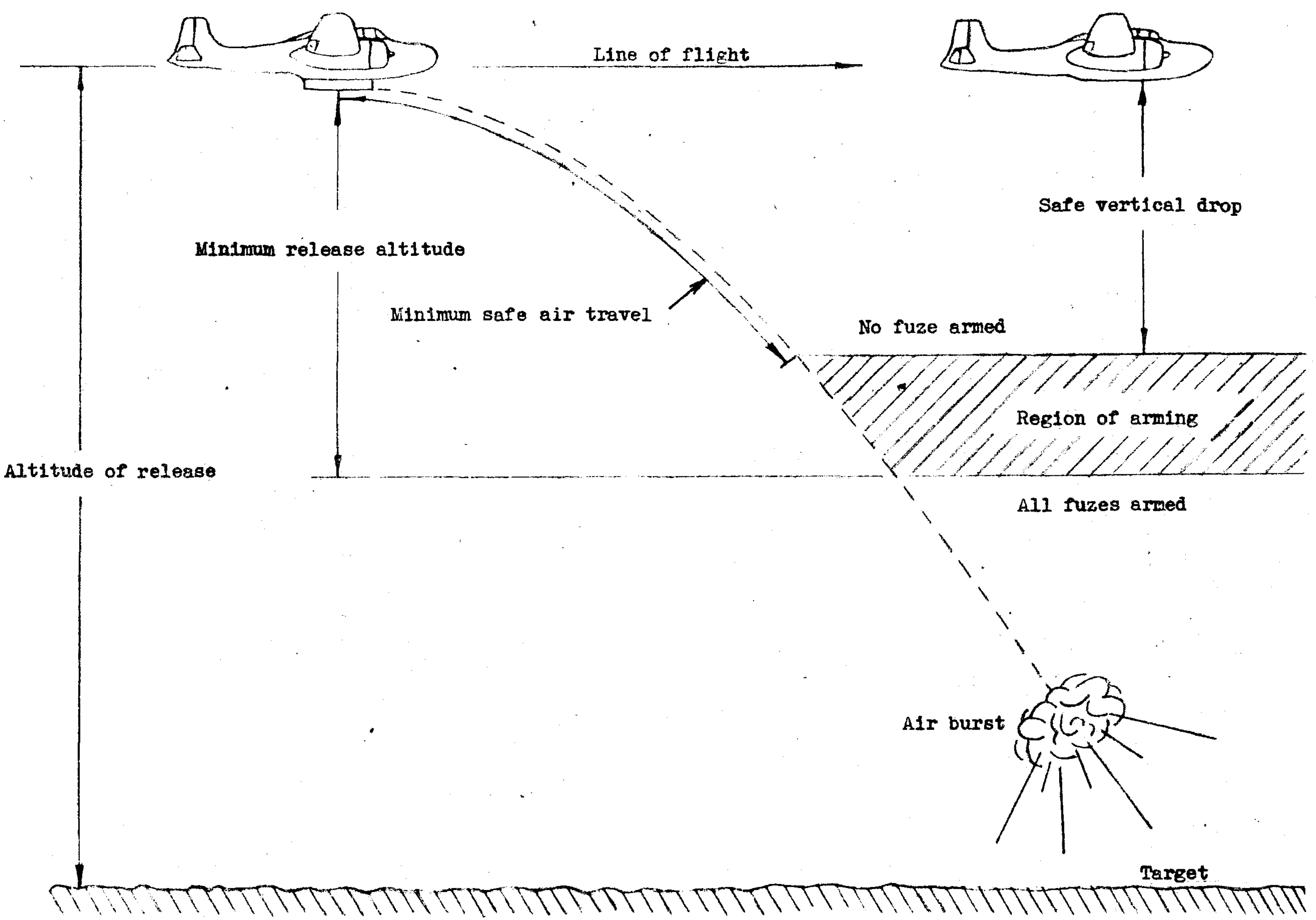


Fig. 11. Schematic drawing showing safety arming features of the VT fuze.

II. LECTURE NO. 2

ELECTRICAL PRINCIPLES OF VT FUZES

by C. H. Page
January 20, 1945

The VT fuzes operate by virtue of certain properties of radio waves. The "waves" are "generated," "transmitted," "modulated," "received," and "detected" — the output of the detector is finally selectively amplified. A discussion of the fuze operation therefore requires defining and explaining the technical terms just introduced. The concepts of "waves" and "modulation" will first be discussed in a general way, then illustrated by a familiar example, and lastly applied to the operation of VT fuzes.

1. Waves

Radio waves are so named by analogy with waves on water. Radio waves cannot be seen, but when represented graphically they require the same illustrations as do water waves.

(a) Water waves. — If we examine a vertical cross section of water with waves on it, we see a picture of the vertical displacement of the water as a function of position (Fig. 1).

Instead of examining the water displacement at various points at the same time, we could examine the displacement at a given point at various times. The water level on a post rises and falls as the waves pass by. A simple sketch would show the level at any given time, and a later sketch would show a different level (Fig. 2).

The behavior of the water level on the post can be represented graphically by plotting water level against time (Fig. 3). Although this looks like a cross-sectional view, it is purely diagrammatic. The original side view (Fig. 1) was a "snapshot," showing how the water level varies with position at a given time. Figure 3 shows how the water level varies with time at a given place. It is the similarity between the two diagrams that characterizes "waves" in general.

(b) Sound waves. — Hearing is associated with the motion of the ear-drum produced by varying air pressure. The "sound waves" can also be

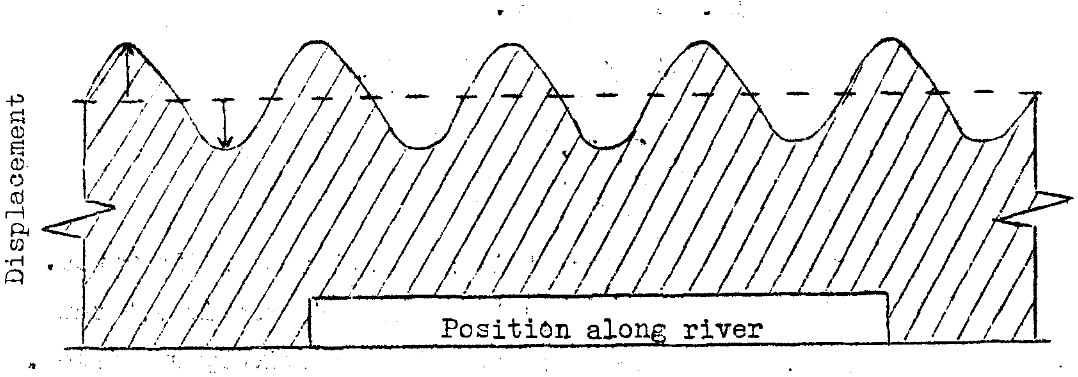


Fig. 1. Vertical displacement of water as a function of position.

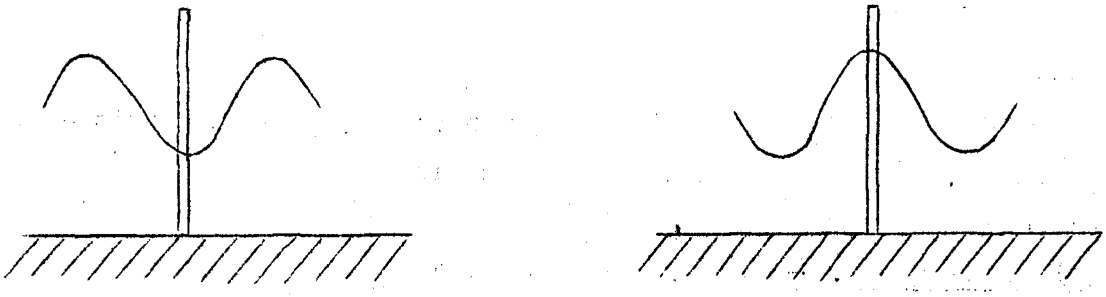


Fig. 2. Variation of water level on a post with time.

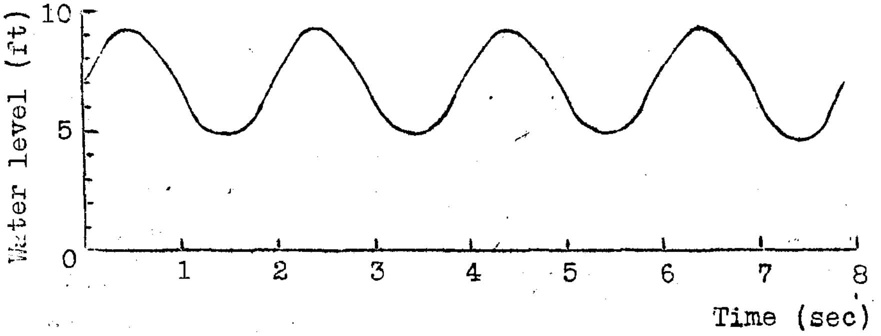


Fig. 3. Graphical representation of variation of water level at a given point with time.

[redacted]

represented by the same sort of diagram as used in Fig. 3 for water waves. Figure 4 is such a diagram for a sound wave.

Two of the chief characteristics of the sound are loudness and pitch. In scientific language these are called amplitude and frequency. Figures 5(a) and (b) represent sound waves differing only in amplitude; the waves in Figs. 5(c) and (d) differ only in frequency.

(c) Electrical waves. — An alternating current can be represented graphically in a manner similar to that used for water and sound waves (Fig. 6). Note the current reversal.

The electrical disturbance called "radio waves" can also be represented in this manner, but the frequency is much higher (Fig. 7).

2. Modulation

All these figures represent "oscillations" of constant amplitude. It is possible to vary the amplitude with time in any desired manner, for example, as shown in Fig. 8. Any variation of the amplitude is called a "modulation." A device to impress a desired modulation onto an oscillation is called a "modulator."

(a) Modulation by a musical note. — Let us consider the modulation of a radio signal by a musical note, as illustrated in Fig. 9. Since the music signal cannot be transmitted by itself, it is placed onto an otherwise steady signal as a modulation. This steady signal acts as a "carrier" of the modulation. The modulated carrier current is radiated by the antenna as a radio wave. The modulated carrier radio wave can be received by an antenna, and so converted from radio waves back into an electric current. To get the music, the modulation must be "detected." A "detector" is an amplitude-measuring device that will not follow the rapid oscillations of the carrier, but that will follow the relatively slow modulation of the amplitude (see Fig. 10).

(b) Modulation in the VT fuze. — A similar chain of modulation, transmission, reception, detection, and amplification occurs in the operation of the VT fuze. The analogy is not perfect, since in the latter case the modulation is not impressed before transmission.

Consider a transmitter with "square" modulation; that is, alternately on and off (Fig. 11). This wave can be reflected back by the earth's surface, and received by the same antenna plus a detector. We shall assume

[redacted]

[redacted]

that the detector does not "see" the local transmitter, but sees only the incoming reflected wave (Fig. 12).

A device for determining the time lag between sending out a pulse and receiving its reflection would indicate the distance to ground. This is essentially the radar principle.

In VT fuzes, the oscillator is not turned on and off, but operates continuously. Both the outgoing and incoming signals are applied to the detector (Fig. 13). Let us consider the effect of time lag of the reflected wave (Fig. 14). In case 1, the reflected wave enters the detector in phase with the local signal, increasing the voltage on the detector. In Case 2, the signals are out of phase, reducing the detector voltage. Figure 15 shows the effect of the phase of the reflected wave on the detector voltage. The phasing of the reflected signal relative to the local signal depends on the height of the fuze above ground, so that the voltage applied to the detector varies in amplitude with height above ground (Fig. 16). If the fuze is mounted on a falling bomb, so that the height above ground is changing with time, we may rotate the figure and relabel it as a curve of voltage versus time (Fig. 17). Thus the motion toward the earth modulates the voltage applied to the detector.

3. How the modulated wave causes the fuze to function

The modulation is detected and amplified, giving a voltage wave whose amplitude increases as the bomb approaches ground (Fig. 18). If this voltage were fed to a loud-speaker, the sound would grow continually louder, and its pitch would rise slowly (because the bomb speed increases slowly).

A "thyratron" is essentially an electronic switch that closes when the applied control signal reaches a predetermined level. When the thyratron operates, it effectively closes a "switch" between the power supply (140 volts) and the electric detonator which explodes the fuze booster charge. The height at which the fuze functions is therefore the height at which the signal from the amplifier reaches the level required by the thyratron. The amplitude of the modulation of the wave applied to the detector, hence the amplitude of the signal applied to the amplifier, depends on the height of the bomb above ground, but not on its speed of fall. The frequency (audio) of the signal is proportional to the vertical component of the bomb velocity,

[redacted]

[redacted]

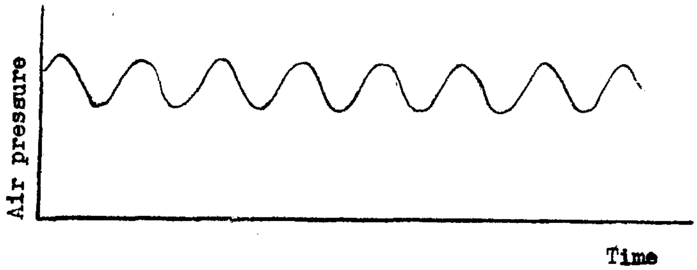


Fig. 4. Graphical representation of sound wave at a fixed point.

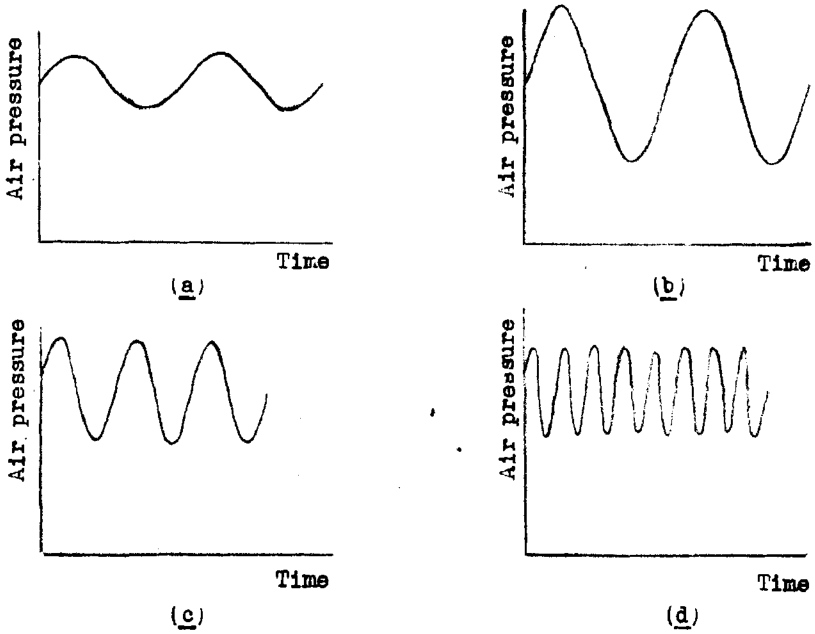


Fig. 5. Representation of sound waves (a) and (b) differing only in amplitude, (c) and (d) differing only in frequency.

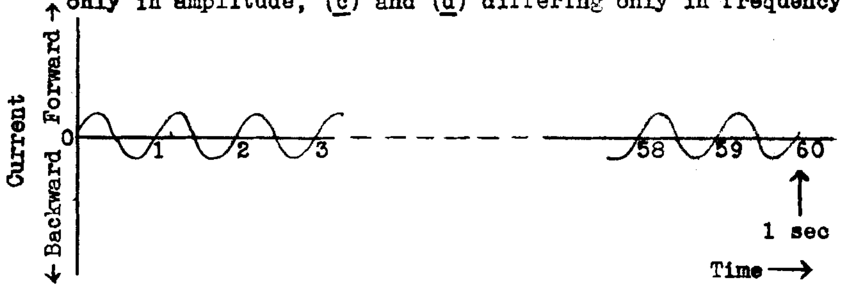


Fig. 6. Graphical representation of an alternating current with a frequency of 60 cycle/sec.

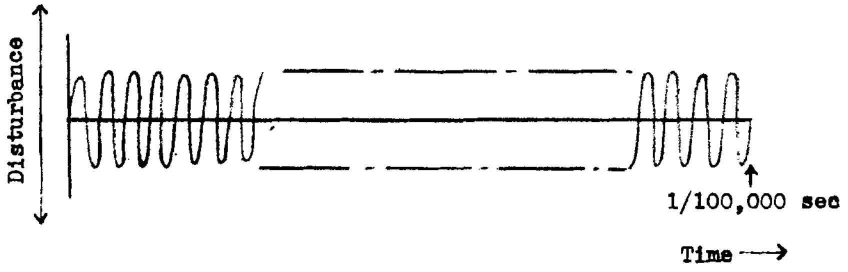


Fig. 7. Graphical representation of radio waves. Note that the frequency is much higher than for the alternating current shown in Fig. 6.

[redacted]

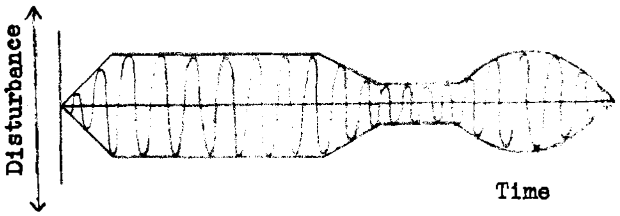


Fig. 8. Variation of amplitude with time, a modulated wave.

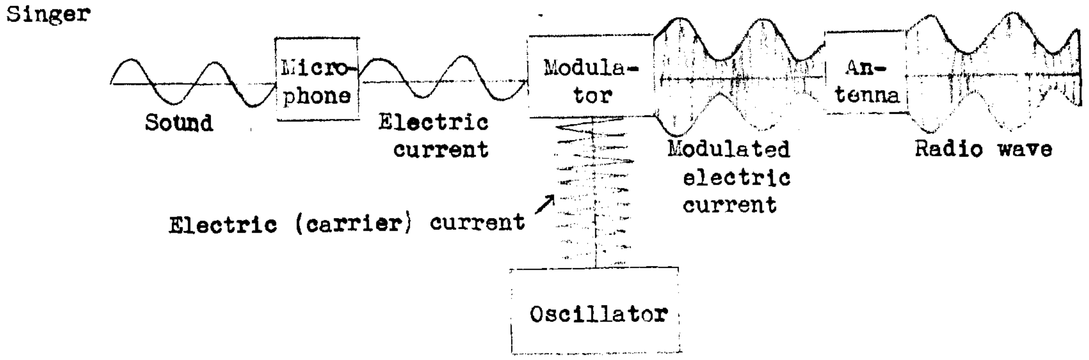


Fig. 9. Modulation of a radio signal by a musical note.

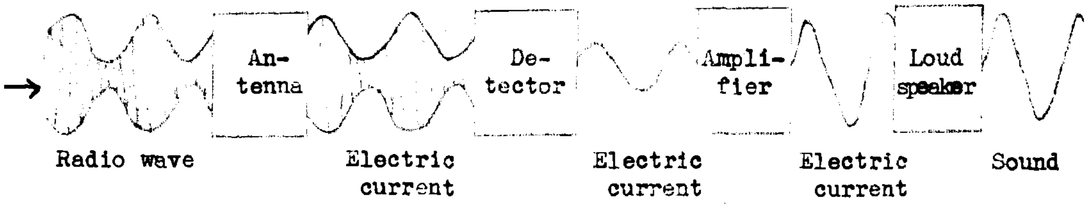


Fig. 10. Schematic diagram of the detection of a modulated radio wave and the production of a sound wave corresponding to the modulation.

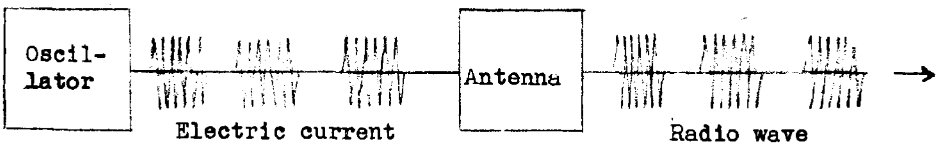


Fig. 11. Transmission of a wave with "square" modulation.

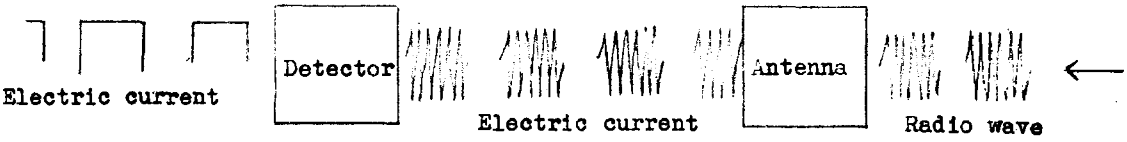


Fig. 12. Detection of a wave with "square" modulation.

[redacted]

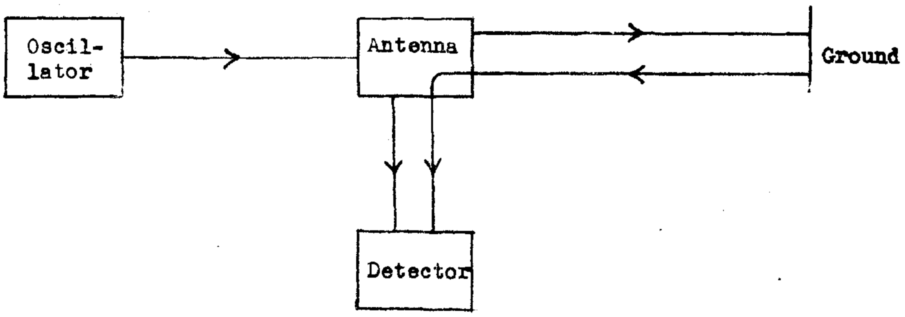
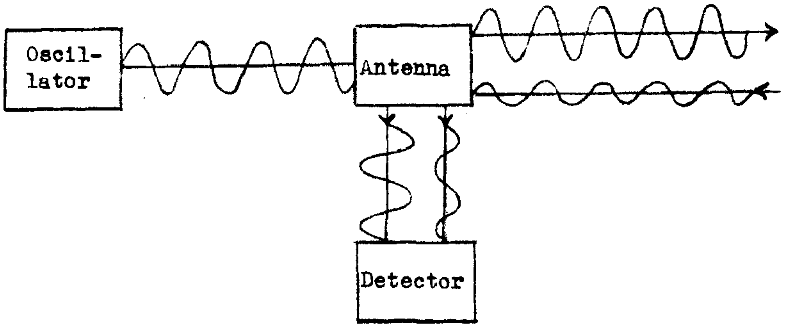
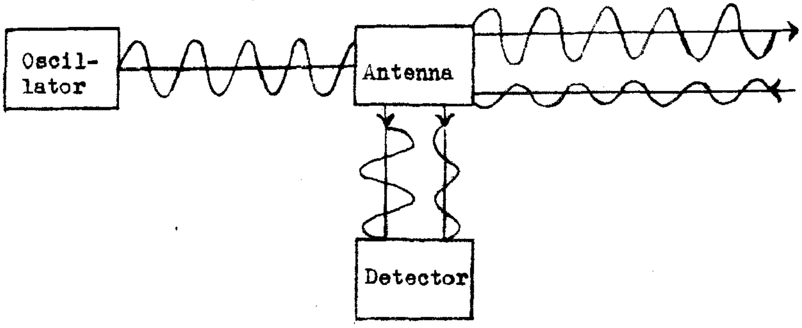


Fig. 13. Schematic diagram showing receipt of both outgoing and incoming signal by the detector in the VT fuze.



Case 1. Reflected wave and outgoing wave in phase at detector.



Case 2. Reflected wave out of phase with outgoing wave at detector.

Fig. 14. Schematic diagrams showing effect of time lag of the reflected wave.

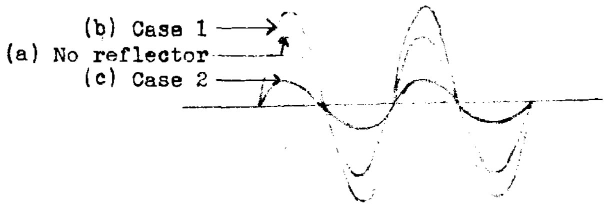


Fig. 15. Graph of detector voltage for (a) no reflector, (b) reflected and outgoing wave in phase at detector, and (c) reflected and outgoing wave out of phase at detector.

[redacted]

[redacted]

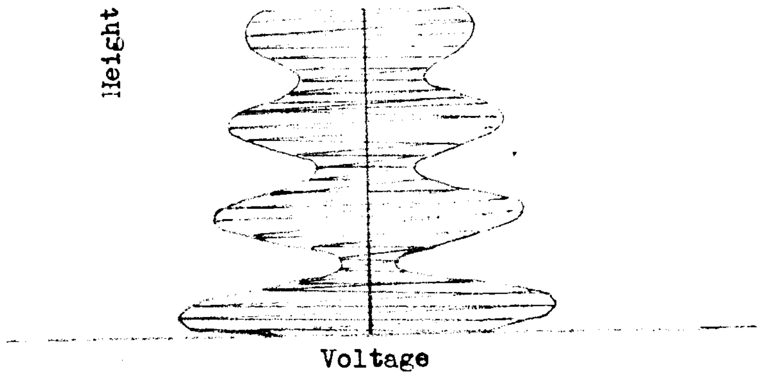


Fig. 16. Variation of detector voltage with height.

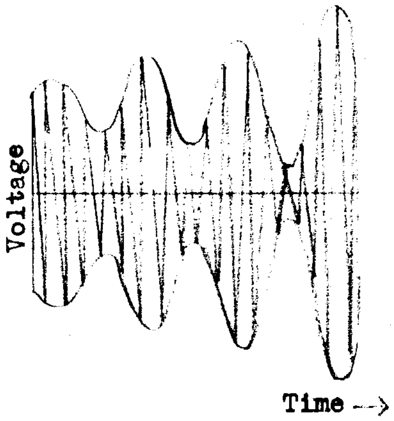


Fig. 17. Detector voltage versus time. The detector voltage is modulated by the changing phase relation resulting from changing height of fuze.

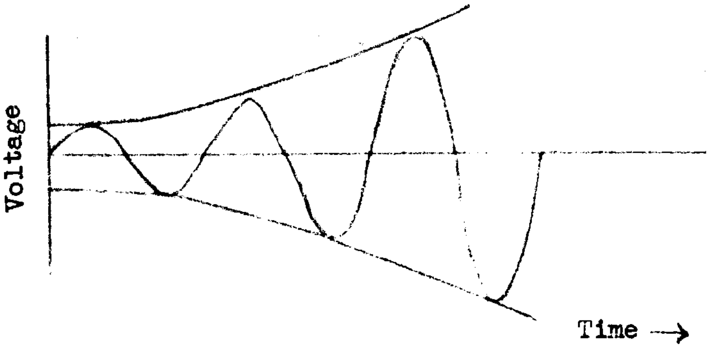


Fig. 18. Voltage wave resulting from detection and amplification of the modulation of the voltage applied to the detector.

[redacted]

but is otherwise independent of height. The gain (amplification) of the fuze amplifier should depend upon audio frequency in such a manner as to give the same function height for any bomb-release conditions. We must now consider the difference between bar-type and ring-type fuzes.

(a) Bar-type fuze. -- The bar-type fuze yields a signal that is approximately independent of the tilt of the bomb from the vertical. Hence the signal amplitude depends on height only, and the amplifier gain should be independent of audio frequency over the range of signal frequencies (bomb speeds) encountered. A desired curve is shown in Fig. 19. The response outside the useful range (160 to 300 cycle/sec) will be discussed later.

(b) Ring-type fuze. -- The ring-type fuze gives weaker signals the more nearly vertical the bomb. But for a given plane speed, "more nearly vertical bomb" means "higher release altitude" and greater vertical component of bomb velocity. Hence there is a definite relationship between bomb tilt and falling speed, or between bomb tilt and audio-signal frequency. Since the weaker signal is associated with higher audio frequency, this effect can be compensated by making the amplifier gain increase with frequency, so that the signal at the thyratron depends on height of the bomb above ground, but very little upon altitude of release. A typical amplifier curve is shown in Fig. 20.

(c) Shape of gain curve for two types of fuze. -- In both fuze types, it is desirable to make the gain at non-useful frequencies as small as possible. This is to minimize effects of "noise," power-supply "hum," and other spurious signals which may be present at frequencies outside the useful range. In practice, the shape of the gain curve represents a compromise between the desired response and the practical limitations of simple reliable circuits. Typical responses are shown in Fig. 21.

The "noise" mentioned can arise from vibration of the internal structure of the vacuum tubes, from vibration of poorly anchored circuit components or connections, from imperfect power supplies, or from improper fuze or bomb fin installation. Any looseness of the over-all assembly of the bomb, from fuze to tail, represents a variable-resistance connection in the fuze antenna, since the entire bomb assembly is the transmitting and receiving antenna.

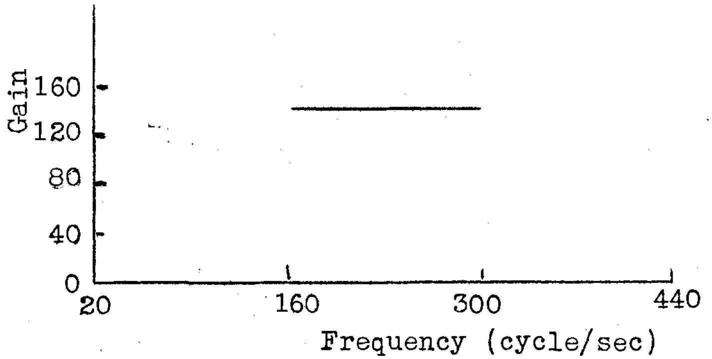


Fig. 19. The relation between gain and frequency that would be desirable for the bar-type fuze.

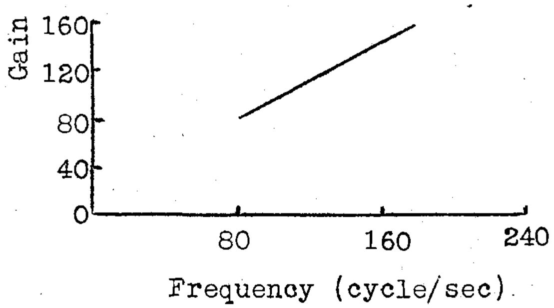


Fig. 20. Typical amplifier curve for ring-type fuze.

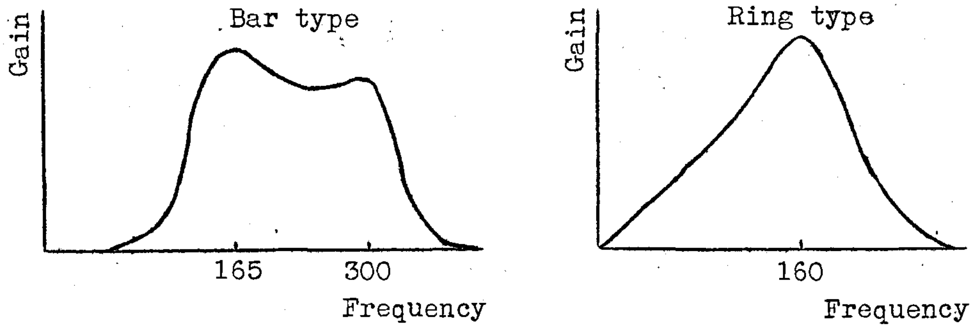


Fig. 21. Typical response curves for bar-type and ring-type fuzes.

4. Power supply and firing circuit

Although VT fuzes of some models use batteries for power, the recent ones use a wind-driven generator (plus rectifier and filter) instead.

The generator consists of a set of fixed coils, and a rotating permanent magnet. Such a device generates an alternating voltage whose frequency is proportional to the rotational speed, and whose amplitude is approximately proportional to speed. A frequency-sensitive loss-load is shunted across the generator, loading the supply more heavily the higher the speed. The net result is to provide supply voltages that are approximately independent of generator speed after the operating threshold is reached. The generator supplies 1.4 volts of alternating current directly to the tube filaments, but the high-voltage plate supply must be "rectified" and "filtered." The rectifier acts like a self-switching device, in that it converts the alternating current (Fig. 22) to a pulsating direct current (no current reversals) (Fig. 23). The pulsations must be smoothed out, or "filtered," leaving a steady average current.

The electrical circuit and its hydraulic analogue are compared in Fig. 24.

The use of a generator power source instead of batteries eliminates storage-life and operating-temperature limitations. There is also a tremendous gain in inherent safety, since there is no electricity available unless the generator is spinning rapidly.

The generator (or battery) will not deliver sufficient current to fire the electric detonator. In each case, a storage condenser (analogous to a water tank) is used as a reservoir to provide a large current (flow of water) for a short time. By the use of a large resistance (small pipe) to make the condenser (tank) fill slowly, it is feasible to incorporate a safety <u>time delay</u> of up to several seconds. The condenser (tank) must be filled to a certain level before there is enough electricity (water) stored to fire the detonator even when the valve is opened. If the valve is opened prematurely, the condenser (tank) "dumps" its insufficient charge harmlessly. In "dud" fuzes, the condenser (tank) will gradually discharge from its slight leakage (seepage), and render the fuze harmless. This occurs sooner in generator-powered fuzes than in battery-powered fuzes, since after the generator stops, there is no source of possible leakage <u>into</u> the condenser. With a battery, safety depends on waiting until the battery is dead.

[redacted]

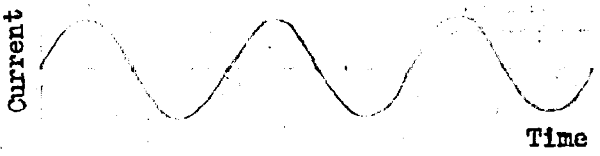


Fig. 22. Alternating current produced by generator

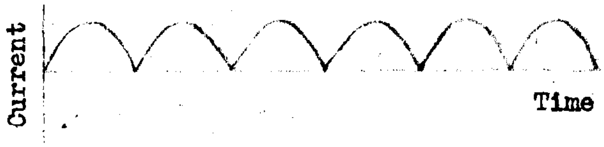
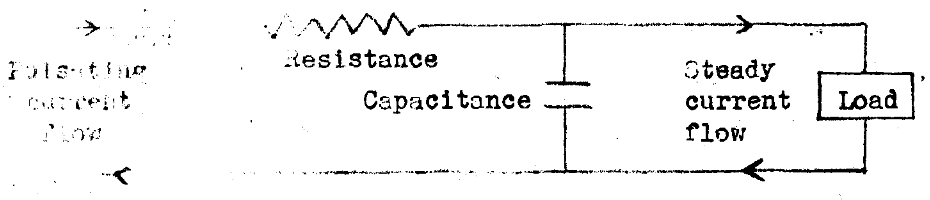
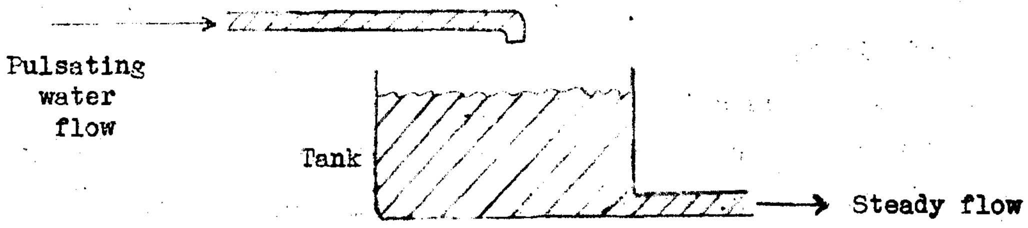


Fig. 23. Pulsating current produced from alternating current by rectifier.



(a) Electrical circuit



(b) Hydraulic analogue

Fig. 24. Electrical circuit to produce a steady average current from a pulsating current flow and the hydraulic analogue to this circuit.

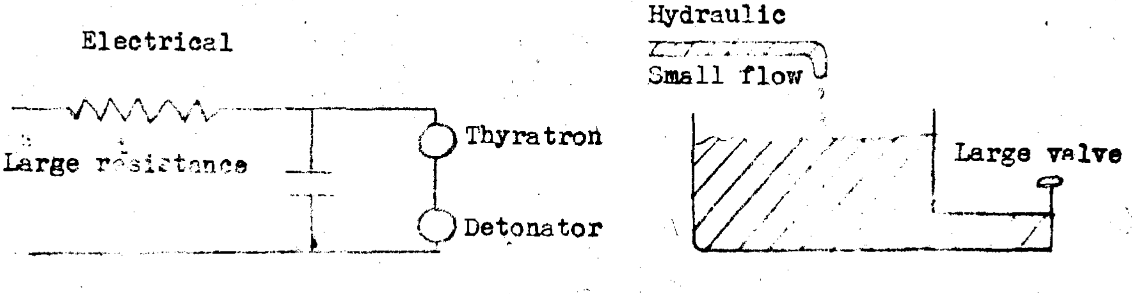


Fig. 25. Electric circuit and hydraulic analogue showing the production of a large current for a short time.

[redacted]

III. LECTURE NO. 3

FACTORS INFLUENCING HEIGHT OF FUNCTION OF VT FUZES

by B. J. Miller
January 22, 1945

1. Introduction

The factors influencing height of function of VT fuzes are the following:

A. Amplifier gain and shaping,
B. (1) Angle of approach to target,
  (2) Component of projectile velocity toward target,
  (3) Reflectivity of target,
C. (1) Radiation pattern,
  (2) Sensitivity of radio unit.

The foregoing grouping is according to the following scheme. The factors in A depend on the unit only. They are built into the unit, and are not adjustable in the finished fuze.

The factors in B are completely independent of the fuze, and are subject to some measure of control by the using arm. B(1) and B(2) are determined by direction and velocity of release, and altitude of release, together with the ballistics of the projectile. B(3) depends on the nature of the target.

The factors in C are determined by the combination of fuze and projectile. For ring-type fuzes, the radiation pattern is determined by the relationship between fuze carrier frequency and projectile dimension (principally, the projectile length); the sensitivity is similarly determined, but does not vary as markedly. For the bar-type fuze, the radiation pattern and sensitivity are much less affected by the combination of fuze and projectile selected, so that good function heights can be obtained with a single model over a variety of projectiles that require two models of ring-type fuzes.

Because of the intimacy of the interaction between these factors, the above-defined separation into groups cannot be maintained in the subsequent discussion and was made originally only for the purpose of emphasizing the factors subject to control.

2. Factors controlling audio output

The fuze functions in the following manner. An outgoing radio wave is reflected from the target back to the fuze. The reflected wave produces a disturbance in the radio unit, which is amplified by the amplifier. When the amplifier output becomes large enough, it fires the thyratron and initiates the detonation of the high explosive. The fuze thus fires when the audio amplifier output is large enough, and we must investigate the factors controlling this output.

The audio output is:

(*a*) Inversely proportional to the height h, except when h is small. In this case, the output goes up more rapidly as h decreases, approaching inverse proportionality to h^2.

(*b*) Directly proportional to the reflection coefficient of the target.

(*c*) Directly proportional to the value of the radiation pattern in the direction of the target.

(*d*) Directly proportional to the gain of the amplifier at the frequency of the disturbance produced by the reflected wave.

(*e*) Directly proportional to the sensitivity of the radio unit.

According to the foregoing list, reducing any one of the factors (*b*) to (*e*) by one half would therefore halve the height of function unless it is already low; low heights of function (less than two wavelengths) would be reduced less drastically, to approximately 70% of the value expected before the change.

3. Reflection coefficient of target

The variations to be expected in item (*b*) will first be discussed. Reflection coefficients to be expected range from about 0.22 to 1.0, according to the following table.

Surface	Reflection Coefficient
Large metal screen*	1.00
Sea water	0.95
Fresh water	0.80
Dry sand	0.35
Ordinary soil**	0.40 to 0.75
Ice, snow	0.22
City areas	0.50

*Several times height of function in each direction.
**Depending on moisture content.

[redacted]

Heights obtained over ordinary soil would then be expected to be about half (or somewhat more) as great as those observed over sea water. However, such a deduction is true only over a fairly homogeneous area. The unit will average the reflection coefficient over an area several function heights on a side; a small puddle of water directly under the trajectory does not give a function height characteristic of a water target.

A question must also be raised about the effect of superposed targets, such as ice over water. Penetration of the radio waves into any of the types of reflectors noted except ice or snow, is very small. Water a few inches deep over a considerable area of land or ice therefore gives a water target, since the waves do not penetrate enough to find out that there is another target beneath. With ice and snow, fortunately, the case is known to be different. The waves penetrate ice or snow to a greater depth, and will be reflected from targets underneath. The extent of this penetration is not known at present, but it is known experimentally that 3 in. of ice over sea water gives a reflection coefficient closer to that of water than of ice; a greater penetration into snow is to be expected.

4. Effect of irregularities in target

While discussing target factors, it is probably well to mention one other factor: that of irregularities. A general slope in the target area is equivalent to a different angle of fall over level ground; small roughnesses (such as bomb or shell craters) will give rise to somewhat greater dispersion in height, with a slight increase in the average. For the effect of very sizable projections such as buildings or trees it is necessary to distinguish between fuze types. The ring-type fuze will tend to function near or slightly above tree tops or building tops if these are not too closely packed and the fuze falls down beside one or a group. For very dense trees or structures, their tops become the reflecting surface, but the reflection coefficient is not very high; a function somewhat above the tops is then expected. Isolated trees or small buildings will not have much effect on the bar-type fuze, especially if they are not directly under the trajectory. Dense foliage or large buildings under the trajectory will give a greater height of function above them than with the ring-type fuze.

Airborne targets will be discussed in the next section.

[redacted]

[redacted]

5. Radiation pattern; angle of approach to target

The radiation pattern, as previously mentioned, is controlled by the combination of fuze and projectile. For the ring type, this is because the projectile is used as an antenna. The direction in which antennae radiate and receive most efficiently is controlled by the relation between wavelength of the radio waves used and antenna length.

For antenna lengths short compared to a wavelength, the maximum radiation is perpendicular to the antenna, falling off at angles more nearly parallel to the antenna, finally becoming zero along the axis. As the antenna becomes longer, the pattern first grows sharper; more and more of the radiation is concentrated along the perpendicular, and less and less at angles a few degrees from the axis. This tendency continues up to a length somewhat greater than $\frac{1}{2}$ wavelength. At 1 wavelength a new type of pattern appears with 2 maxima, at about 45° from the axis, with zero along the axis and zero perpendicular. At a length equal to $1\frac{1}{2}$ wavelengths, 3 maxima appear, one perpendicular to the antenna, one about 30° forward, and one about 30° back, and so on.

It is to be noted that for most bombing applications, one is concerned with angles from the axis less than 30°. From the foregoing discussion, it is clear that the energy radiated in this direction by a given fuze will vary, depending on the length of the bomb to which it is attached, and may in some cases be too little to give a good height of function. This occurs, in fact, if the wrong combination of fuze and vehicle is selected; and results in the necessity for making two ring-type fuzes whose most important difference is in the wavelength of the radio waves.

The efficiency with which radio energy generated by the fuze is accepted and radiated by the antenna (regardless of direction) also varies as the pattern does, and gives rise to some variation in sensitivity of the radio unit; but this variation is much less than the variation in height due to pattern changes.

The bar-type fuze does not use the bomb as an antenna, but has its own antenna. This is short compared to a wavelength and therefore most of the radiation is perpendicular to the antenna, or along the axis of the bomb. For this reason, it is easier to attain large heights of function at steep angles of approach. Despite the bomb's not being connected to the antenna,

[redacted]

it has some influence on the pattern because of its reflection properties. For this reason, there is still some variation of height of function to be noted on different vehicles, larger vehicles as a rule giving lower heights.

One more point should be made before discussing other factors. The ring type of pattern -- zero along the axis with maximum out to the side -- is used for airborne targets with rocket ammunition. A good shot will thus not be detonated prematurely, and misses are detonated alongside the target. It should be remembered that ring-type fuzes on bombs will have a similar action, although their amplifier design is not such as to give optimum sensitivity at the audio frequency encountered in the airborne-target application.

6. Amplifier gain and shaping; projectile velocity

The amplifier shaping is designed to work with the radiation pattern to reduce spread in height of burst. In the bomb application, steep angles and high (vertical) velocities go together, and flat angles and low velocities, since steep angles occur with high-altitude releases, and flat angles with low-altitude releases. For the ring-type fuze, steep angles give small signals, and flatter angles, larger; thus the amplifier should have high gain for the steep-angle signals and less for the flat-angle signals. The difference between the two is frequency; the frequency of the signal is proportional to velocity, and is thus greater when the angles are steeper. The amplifier is therefore constructed with higher gain at higher frequencies up to the limit of the frequencies expected. (Gain is sharply reduced above these frequencies to avoid troubles with microphonics and other types of noise.)

For dive bombing, the relationship between angle and velocity of approach is different, and different heights are to be expected.

For the bar-type fuze, the radiation pattern varies slowly with angle, so the same gain is required at different velocities. The amplifier is therefore constructed to have approximately the same gain at all frequencies expected.

[redacted]

7. Use of rockets from airplanes

These considerations have an important bearing on the use of rockets from airplanes against targets on the ground. If too flat an angle is used, the velocity toward the earth is very small and the frequency of the resultant signal very low. At this frequency the amplifier will have very little gain and a low height of burst will result. A second factor also argues against the use of such flat trajectories. Angles of approximately 15° below horizontal will give reasonable heights of burst with most rocket fuzes. However, at such low angles the natural dispersion in height of function due to unavoidable variations in sensitivity will give rise to a dispersion in range that may be annoying with certain types of targets. This dispersion will not be large enough to reduce effectiveness if angles of 25° or greater are used.

[redacted]

[redacted]

IV. LECTURE NO. 4

MECHANICAL CONSIDERATIONS IN THE DESIGN OF VT FUZES

by J. Rabinow
January 23, 1945

1. Introduction

The general mechanical requirements for the design of proximity fuzes, both of the photoelectric and of the radio type, are fairly simple, particularly so if only nose fuzes are being considered.

The arrangement of the main components breaks down almost automatically into the following. In the radio fuze the antenna is usually the front element followed immediately by the antenna insulator. In the photoelectric fuze these two elements are replaced by the photoelectric cell. The natural location of the amplifier is immediately behind these. This is in turn followed by the power supply which may be either a battery or a generator. The arming system, together with the detonating element, falls logically behind the power supply, and the whole of the fuze is terminated by a booster cup as is the practice in mechanical point-detonating fuzes.

The design of the mechanical details of the proximity fuzes presents some very difficult problems. Owing to the extreme sensitivity of proximity fuzes to noise or to physical disturbances of any kind, the mechanical design must be such as to insure the greatest possible stability and freedom from vibration. This is particularly true for nonrotating projectiles for which the fuzes were designed. In the rotating projectiles centrifugal forces tend to tighten up all the elements so that the looseness in the mounting of the various components is taken up. In a nonrotating projectile moving through the air at customary speeds, the forces on the internal elements are quite small and cannot be depended on to eliminate any slack in the mountings.

Another consideration, which is not inherent in the design of our particular fuzes, but which is of extreme importance in all fuze designs, is the requirement for the smallest possible size. Since the vehicles that are used with the fuzes under consideration are also designed for mechanical fuzes, every effort was made to keep the size of the proximity fuzes somewhat

[redacted]

comparable to the others. This was not always possible, of course, and the original models of the proximity fuzes were very much larger. The size has been, and is being, constantly reduced, and all indications point to ultimate sizes comparable to present-day mechanical fuzes.

The safety and arming characteristics of proximity fuzes, while in general similar to those for mechanical fuzes, differ in one important respect from the latter. It is not sufficient to make a proximity fuze merely "bore safe" while on the launcher. Since these fuzes are influenced by the presence of ground or any large masses in their vicinity, they must be kept unarmed until they are at a sufficiently safe distance away from the launchers. The foregoing requirement for a minimum safe air travel (Min SAT) is also necessary because proximity fuzes are sometimes subject to "early functions."

To accomplish arming in the battery fuze, designed for rocket applications, advantage can be taken of the presence of setback acceleration so that the arming system can be triggered by this acceleration and no external arming device need be used.

In the generator models some form of turbine or propeller is necessarily present, and the rotation of this element can be made to operate an arming system through the use of gears. This is done in the bomb fuzes, while in the case of rocket fuzes, setback is sometimes employed in conjunction with the rotation of the propeller to decrease still further the possibility of accidental arming.

2. The mechanical characteristics of the various fuzes

Perhaps the simplest way of treating the mechanical design of the various proximity fuzes described here is to treat them in the order of their historical development.

(a) Arming. — The first production fuze developed for nonrotating projectiles were the photoelectric fuze now known as T4 and the radio fuzes known as T5 and T6. The original emphasis in the design of these fuzes was for plane-to-plane applications. This required a short arming distance for close fighting, and since the fuzes were to be used on rockets, which were launched from tubular projectors, the use of arming wires was considered undesirable. It was also the opinion of the mechanical development group that arming wires are unsafe, being subject to external influences, both human and otherwise.

It was decided that since setback was always available in rocket applications, the arming system would be designed to operate by the acceleration of the projectile. The required distance to complete arming was obtained by introducing a time delay after the cessation of acceleration that would provide sufficient air travel to get the fuze to a point a safe distance ahead of the projector.

Other arming systems were considered and will be mentioned briefly here. One was the manual system used in the original British fuze where a powder train was completed by the turning of a shaft projecting through the side of the fuze shell. If the round were not fired, one of the crew members had to remember to reset the safety to the original safe position.

Several systems requiring arming wires were seriously considered. The arming wires would have had to be inserted into each fuze and would have remained on the launcher when the round was fired.

Air pressure could be employed to operate a diaphragm or a bellows-type of switch and arming mechanism, but this method while actually tried was open to the very serious objection that the air intake ports could fill with mud and water and thus be subject to the vagaries of poor handling and bad climatic conditions.

Spring-driven clock mechanisms of various types were considered where the clocks were either started by setback, air pressure, or arming wires. They were discarded owing to the complexity of design, high cost, and because of the inherent lack of safety of a clock mechanism.

As has been stated, the solution chosen was to make use of the acceleration of rockets, which in the original M-9 rounds was of the order of 150 to 300 *g* for approximately $\frac{1}{4}$ sec. It was soon discovered that the use of simple weights supported by springs was unsatisfactory. All simple devices of this type, whether the motion of the weight is linear or circular, are subject to the fault that a sudden violent shock in the correct direction will start the weight moving, and the weight will then move to the completion of its arming cycle by its own inertia. By interrupting the motion of such a weight so that it has to stop several times on the way to the completion of its arming cycle, we obtained a device that was quite safe against accidental shocks. To operate such a device, the acceleration has to be sustained so that the operating weight must start its motion anew after each stop. One method of accomplishing this is to use a flutter-wheel escapement operated by an unbalanced weight. The weight moves back in a series of steps and when it finally reaches its extreme rear position, it trips the trigger which completes the first step of the arming cycle. At the end of acceleration this weight can be made to return slowly to some other position and complete the total arming cycle in any desired time. The unbalanced weight is restrained against motion by a spring so that some minimum value of acceleration must be experienced before the weight starts to move at all. In the T4, T5, and T6 fuzes this limiting value is 75 *g*. In other words, unless the unit experiences an acceleration of more than 75 *g*, the arming weight will not leave its normal position. The mechanism is so arranged that the acceleration must last for at least 0.1 sec at approximately 100 *g* before the first part of the arming cycle is completed. If the acceleration lasts for less than this time, the weight will return to its initial position and the arming mechanism will be again in the safe condition.

The arming, as used in these fuzes, is so designed that the *A* and *B* circuits are closed when the weight reaches its lowest position in approximately 0.1 sec as mentioned above. The powder train and the detonator circuit is not completed, however, until approximately 0.7 sec after cessation of the acceleration.

There is, in addition to the mechanical safety device just discussed, an electrical RC (resistor condenser) circuit that delays the building up of the voltage on the thyratron plate for a time which may vary from a fraction of a second to several seconds. The time marked on the outside case of the safety mechanisms is the total time to completion of the mechanical plus the electrical arming.

(b) *Generator-powered fuzes T50 and T51.* -- Soon after the beginning of the development of the work on battery fuzes, it became apparent that certain advantages were to be gained by the replacement of the battery by a generator. As is well known, the shelf life of the battery at best is rather short, while that of a suitably built generator is at least equivalent to that of the other components of the fuze. While the current required by the fuze is mainly of the d-c type, direct-current generators require commutators

with their attendant noise and are larger physically than alternating-current generators of equal power. Alternating-current generators also have the further advantage that the field can be the rotating component, particularly when permanent magnets are employed. This leads to stationary coils and relatively simple mechanical design.

(i) Generators. The generators as used in our fuzes are of the 6-pole variety having laminated stators and solid Alnico rotors. The Alnico rotors are smooth disks 0.25 in. thick and approximately 1 in. in diameter. The disk is magnetized so as to have three north and three south poles equally spaced around its periphery. There are two sets of windings on the stator. One is a low-voltage winding for the filament supply and the other is a high-voltage winding for the B supply. The filaments are operated directly on a.c. The high-voltage supply is rectified by a selenium-cell bridge rectifier giving a d-c output sufficient to operate the fuze and to charge the detonator firing condenser.

(ii) Speed of operation. The discussion of the electrical features of this fuze is, of course, covered in another paper (see Lecture No. 2). In order to keep the dimensions of the generators to a minimum and to keep the a-c ripple from being amplified by the rather sharply tuned amplifiers, very high speeds are employed. In the T50 series of fuzes speeds of the order of 12,000 to 50,000 rev/min are attained. These high speeds result in problems of bearing design, particularly if the fuze is mounted in the nose of the projectile. A propeller or turbine running at a very high speed must also be able to withstand the very considerable thrust of the impinging air stream. This is particularly true of rocket applications where supersonic speeds are the rule rather than the exception.

(iii) Propellers. The propellers may be either bakelite or metal and have a pitch which, while differing among the various fuzes, is of the order of one revolution for 2 ft of air travel. Since these propellers are mounted in close proximity to the oscillators in the radio fuzes, any vibration in the propeller bearings is communicated to the radio components and may set up noise which would result in improper functions. The propellers in the fuzes as they are built at present are individually balanced so that the residual unbalance and the resulting vibration are kept to a minimum.

(iv) Bearings. Because of the large thrust experienced by the propeller, ordinary sleeve bearings were found to be unsuitable and ball bearings are employed. There is very little thrust on the generator shaft and here either ball bearings or sleeve bearings can be used. The sleeve bearings are of the porous bronze variety which store oil in the pores of the material.

(v) Coupling shafts. The propellers are coupled to the generators by insulating bakelite coupling shafts. This is done because the propeller is usually mounted in the antenna, while the generator is below the oscillator in the grounded part of the fuze. A metal shaft would act as a short circuit across the antenna and cannot be employed. The bakelite coupling shafts drive the generators, which are equipped with metal shafts, and the bottoms of the generator shafts, in turn, are coupled to the gear trains.

(vi) Safety feature. One of the inherent safety features of the fuze using permanent-magnet generators is that there is appreciable magnetic lock-in torque at the generator rotor. This means that the fuzes can be so designed that winds normally encountered on the ground are of insufficient velocity to break this magnetic lock and operate the fuze.

(vii) Arming. The arming systems of the generator fuzes take advantage of the presence of the rotating power supply. This is particularly fortunate in the case of the bomb fuze since accelerations of appreciable magnitudes are not present in this application. It is a relatively simple matter to extend the generator shaft and to couple to it a gear train which aligns the powder train and closes the appropriate circuit at the end of any desired number of revolutions. In the generator fuzes, the electrical detonators are mounted in movable rotors so arranged that when the detonator is in the "safe" position (out of line with the explosive train), it is also completely disconnected from the firing circuit. The gear train is so designed that after the fuze has traveled through the air for a required distance, the detonator is brought into alignment with the rest of the explosive train and at the same time is connected to its firing circuit. The standard gear train as used on the bomb fuze has a gear reduction of 7803 to 1 and is usually set so that an air travel of approximately 4000 ft is required to arm the fuze.

The rotor carrying the electrical detonator is driven by the gear train through a 3/8-in. shaft. The detonator rotor itself is equipped with a small transfer pin which engages normally with a groove in the drive shaft. When the rotor is turned to the proper position for arming, the transfer pin is driven by an internal spring into a hole in the outside housing so that the rotor is locked to the housing and at the same time disconnected from the drive shaft. The drive shaft continues to rotate until the fuze is set off.

In the latest designs of our bomb and rocket fuzes the position of this arming rotor can be checked from the outside by means of a pin which is made to pass through the booster cup, the interrupter plate, and the detonator rotor itself. The fuzes are normally shipped with this pin inserted and it has to be removed before the fuzes are inserted into the vehicles. All that is necessary in order to check the position of the rotors subsequently is to reinsert the pin.

In the T51 series of fuzes the mechanical system is exactly like that of the T50 which was discussed in the foregoing, and the fuzes differ only in the use of a dipole as against the circular antenna.

(c) T82 fuzes. — Some radical departures from the mechanical arrangement described in the foregoing were achieved in the design of the T82 series of fuzes. This fuze was a later development, and it was deemed desirable to eliminate some of the difficulties experienced with the propellers and the high-speed coupling shafts of the T50 fuze. In the T82 fuze the propeller has been replaced by a radial-flow turbine rigidly connected to the generator shaft. This high-speed rotating system is located in the base of the fuze with the generator actually inside the fuze well of the bomb. The air is delivered to the turbine through a central duct approximately 3/4 in. in diameter, and the turbine exhausts through two side ports near the base of the fuze. This fuze is of the dipole-antenna variety with the oscillator, as formerly, in the extreme forward part. The placing of the generator in the fuze well, aside from the greater compactness of this arrangement, also overcomes some of the vibration problems encountered in the previous designs. The rigidity imparted to the mounting by the very heavy nose of the standard bombs results in a considerably lower amplitude of vibration throughout the whole fuze. This in turn is reflected in lower noise levels and the greater resultant sensitivities which can be achieved with this design.

There is a gear train in the T82 very similar to that used in the T50 which terminates in a 3/8-in. shaft slotted to receive the same detonator rotor as in the fuzes previously described. Identical detonator rotors and booster cups are used in the T50, T51, and the T82 fuzes.

3. Variable-distance arming

As experience was gained in the development work on bomb fuzes, it became apparent that an adjustable arming delay would be a very desirable feature. It was, of course, suggested that the fuze be modified so that an externally setable Min SAT could be added to the fuzes. The pressure of time and production difficulties, however, ruled this out, and several externally added delays were tried. The first practical system consisted of a cover that fitted snugly over the fuze and was equipped with its own propeller and gear train so arranged that it could be made to fall off at the end of any desired length of air travel.

Another method that was tested and that was finally adopted was the use of a relatively small extended arming device that was also equipped with a propeller and its own gear train, and that can also be set to fall off and release the fuze propeller after any desired air travel. In the designing of this mechanism, simplicity and safety were the main requirements. The dial which sets the Min SAT is also the release mechanism. The gear train is so designed that the failure of any part should normally result in a dud. While the original production model -- the T2E1 -- is equipped with only one dial, the expected modification -- T2E2 -- will be equipped with two dials placed on opposite ends of the main shaft and so arranged that much greater visibility under the difficult conditions in the bomb bay will be attained.

Some of the advantages of using the T2 besides the additional safety provided in the longer air travel to arming are that the fuze proper operates for a considerably shorter time than it would without the device and, therefore, is less likely to malfunction. There is also less warning to the enemy of the approach of the fuze since the fuze is "dead" until the arming device falls off. The use of the T2 also permits a fuze with a built-in air travel of the minimum amount to be used for the various applications.

4. Generator fuzes for rockets

While the original T50 series of fuzes was designed for bomb use, experiments proved that with certain electrical and mechanical modifications the fuze would be suitable for use on rockets as well. The model of the T50 that was converted for rocket use is now known as T2004. It was designed primarily for the longer-burning, low-acceleration type of rockets. The acceleration encountered in these rockets is between 10 and 50 g, and the burning times vary from a fraction of a second to perhaps two seconds, depending on the temperature of the propellant and the type of rocket. The burning distances vary between 300 and 2000 ft.

These variable characteristics of the rockets present some very nice problems in the design of the arming mechanism. Since approximately 1000 ft of air travel is required as the minimum safety for the arming mechanism, it is quite apparent that in some cases the rocket may still be burning and accelerating when it reaches the end of this travel distance. If the fuzes were all to arm at 1000 ft, the burning and acceleration might not be over in all cases. In order to get the shortest possible arming characteristics into the design of the T2004, a special gear train and arming system was designed which has the following characteristics. The propeller is locked out against turning by the usual arming wire. The final gear in the gear train is not a complete gear wheel having 38 teeth, as in the bomb fuze, but is cut down to a small sector which carries only 5 teeth. This sector is firmly riveted to the arming shaft. There is a coil spring mounted around this arming shaft which tends to drive the shaft, and therefore the detonator rotor, into the armed position. The teeth on the gear sector are normally in mesh with a driving pinion and thus the arming shaft is kept in the safe position.

The gear train is equipped with a setback weight so arranged that it operates a dog in the path of the low-speed gear sector. If the arming wire were accidentally pulled out before the rocket were fired and the propeller began to turn, this dog would stop the rotation of the low-speed shaft with sufficient force to cause one of the driving pinions to strip its teeth. The unit would be permanently injured and would remain a dud. If properly fired, however, the arming wire is withdrawn automatically at the same time as the setback weight moves toward the rear of the rocket and removes this dog detent out of the path of the low-speed gear sector. The propeller then drives the gear train for 100 revolutions, which is sufficient to disconnect the gear sector from its drive pinion. The detonator rotor which is connected to the gear sector by the low-speed shaft is then turned through 90°, or half of its total arming angle, to an intermediate position where it is held by a special stop on the setback weight until the acceleration is over.

When the acceleration is terminated, the setback weight is driven forward by its retaining spring and permits the gear sector to complete the next and final movement driving the detonator rotor into its final armed position.

In this manner the fuze cannot be armed unless it experiences simultaneously both an air travel of approximately 300 ft and an acceleration of at least 10 *g*.

The mechanical arming, as explained above, is completed almost immediately at the end of acceleration or burning.

There is an additional electrical safety in the T2004 consisting of an RC network which delays the arming for approximately $\frac{1}{2}$ sec longer as explained in the paper covering the electrical fundamentals (see Lecture No. 3).

5. Concluding remarks

The fuzes described in this paper are those that were actually put into production and that have by now reached the services.

It goes without saying that a great many experimental models were designed and built, and a great many mechanical assemblies together with various types of arming systems were tested. We do not wish to leave the impression that we claim the systems described here to be necessarily the best, but the pressure of time was so great during the development of these devices and the requirements were often so uncertain at the beginning of each program that the best solution was not always possible. Improvements are continually being made, and it is hoped that each succeeding design will not repeat the errors of its predecessor, although it is realized that each will have its own faults.

[redacted]

It is very difficult in the laboratory to simulate the conditions actually experienced in the field. Every effort was made to anticipate the field conditions. The advice of the men in the services who have to handle this equipment was sought and listened to with respect and interest. If the fuzes discussed here fall short of perfection, it was not for lack of effort on the part of the men and women who did the development work.

[redacted]

V. THE USES, EFFECTS, AND LIMITATIONS OF VT FUZES

by H. Diamond
January 20, 1945

1. Introduction

Since it has only recently become practicable to provide an air burst at a relatively controlled position with respect to the target, it seems sensible to consider the fuzes that accomplish this as tools whose effectiveness must be determined experimentally. Obviously all of their possible uses cannot be predicted. It is possible that some of those that we advance are not practicable, and it is even more probable that from experience in other fields, many other uses for them will be found. Certain tactical situations have already appeared wherein the use of an air burst appears to be warranted. These include situations calling for:

(1) Fragmentation effect against partially shielded personnel or against other soft targets, using bombs or rockets.

(2) Distribution of incendiary material, using Chemical Warfare bombs or modified gasoline tanks filled with napalm-gasoline-gel.

(3) Distribution of nonpersistent gas for Chemical Warfare purposes.

(4) Blast effect produced by a large (4000-lb) bomb, for building or jungle clearance.

(5) Mine clearance, using bombs.

(6) Attack against aircraft, using bombs or rockets.

(7) Miscellaneous uses, such as for attacking E and R boats, or for opening parachutes on stores containers bearing supplies to encircled troops.

2. Performance of the fuzes

Before discussing the increased effectiveness of an air burst in these particular applications, I would like to present some data on the reliability and quality of the VT fuzes that we have developed for rockets and bombs.

(a) Rocket fuzes. -- As you know, two battery-powered rocket fuzes were developed in 1942, of which there are several hundred thousand on the shelf.

[redacted]

One is the T5, for air-to-air use. In tests of quality, determined by firing at a high angle from the ground or by firing from a tower against a plane suspended in the air, the fuze functioned properly about 80% of the time, functioned early[1] about 15% of the time, and less than 5% were duds. The other battery-powered fuze is the T6, for ground-to-ground use. At its maximum range it functioned properly[2] 75% of the time, functioned in mid-flight 20% of the time, and about 5% were duds.

A generator-powered rocket fuze, called the T30, is also being developed -- a conversion of the T50 bomb fuze which arms a short period after the completion of burning in the rocket motor. It is designed for air-to-air use at about 400 yd minimum range and has scored 85% proper functions, 12% early functions, and 3% duds. A companion fuze, T2004, for air-to-ground use, has somewhat better performance.

(b) Bomb fuzes. -- Table I is a record of the performance of production-model bomb fuzes that have been tested at Aberdeen under standard conditions (that is, released from 10000 ft altitude at 200 mi/hr true air speed), and that have been accepted as satisfactory.

Table I. Performance of production-model bomb fuzes tested at Aberdeen.

Release height 10000 ft
Air speed 200 mi/hr

Fuze Type	Number of Lots	Date	Number Units Tested	Type of Function: Proper (%)	Early (%)	Dud (%)	Height over Water (ft)
T50E1 (Prototype of T89, T91)	52	Before 11/15/44	1067	80.5	11.2	8.3	33
	22	From 11/15/44 to 1/15/45	--	86.5	11	2.5	36
T50E4 (Prototype of T92, T90)	45	Before 11/15/44	897	79.0	15.9	5.1	40
	21	From 11/15/44 to 1/15/45	--	85	11	4	34
T51	27	Before 11/15/44	298	86.5	12.1	1.4	140
	16	From 11/15/44 to 1/15/45	--	87	12	1	113

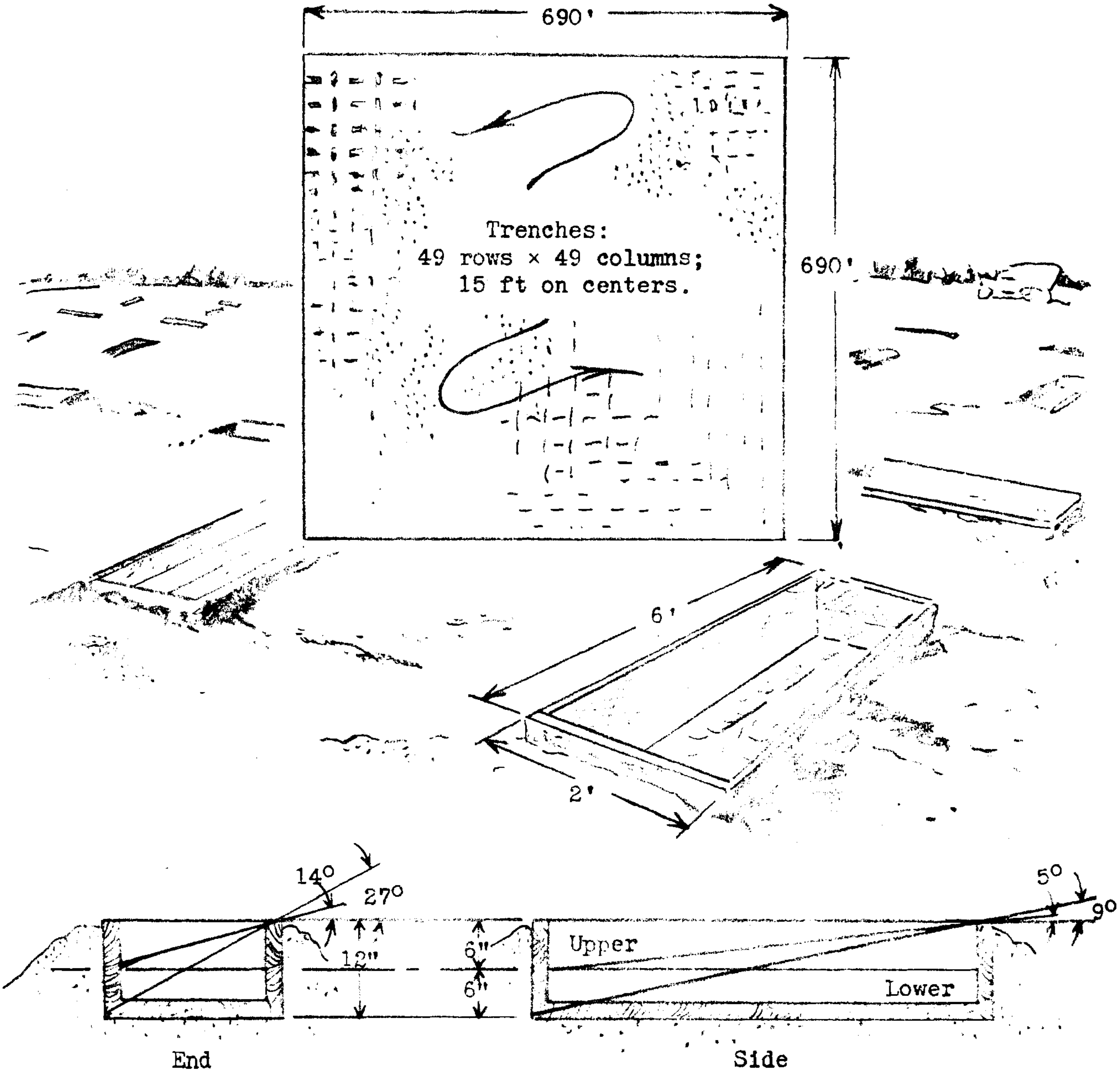
---

[1] An early function is one that occurs shortly after mechanical arming at 300 yd.

[2] Proper functioning increases as the range is reduced.

[redacted]

[redacted]



Sectional views

Fig. 1. Fragmentation effect field.

[redacted]

In-train performance will be discussed under "Limitations" (Sec. 4). The over-all performance of the fuzes can be considered to be 80% proper. Through increased effectiveness (see Sec. 3), they offer an advantage in certain uses over contact fuzes that have greater reliability.

3. Uses

(a) Fragmentation effects against entrenched personnel. -- A recent test of this effect was made at Eglin Field. The results have not yet been released formally by the AAF, but they have been made available for this conference through the courtesy of General Coupland. The purpose of the test was to compare the effectiveness of bombs burst in the air with that of bombs burst instantaneously on contact. The effect was measured by the number of casualties per bomb (or equivalent load of M1A1 clusters), each casualty being represented by one or more bomb-fragment perforations through a single plywood panel 3/4 in. thick. The panels of plywood were placed at the bottom of vertical-walled slit trenches, 2 × 6 × 1 ft, the last dimension being the depth, and the effect field contained 47 rows and columns of these trenches spaced 15 ft on centers (making a square effect field 690 ft on a side with 2209 slit trenches). (See Fig. 1 for details of trenches.) Each of the casualty values given in Table II is an average of the number of casualties obtained with five to seven bombs (or clusters) of a given type that burst at heights grouped about the average height stated. All values for average casualties are subject to a probable error of less than 20% except contact bursts which have a probable error of less than ½ casualty.

Table II. Casualties produced in 2 × 6 × 1 ft slit trenches by M-81, M-64, and M1A1 bombs burst at varying heights. Shielding of 12 in. assumed.

M-81		M-64		M1A1	
Height (ft)	Casualties	Height (ft)	Casualties	Height (ft)	Casualties
Contact	0.7	Contact	1.2	Contact	0.6 per single cluster
16	11	19	15		
30	15	50	26		
70	14				

The foregoing figures are based on an assumption of 12-in. shielding; that is, casualties were counted only for large-fragment-perforation of the bottom panel. If, in addition, the number of large fragments perforating the lower 6 in. of the side walls is counted, casualties corresponding to 6-in. shielding may be computed (Table III). Similarly, by considering all of the heavy-fragment-perforations, casualties corresponding to 0-in. shielding may be computed.

Table III. Casualties produced by M-81, M-64, and M1A1 bombs burst at varying heights assuming 6-in. and 0-in. shielding.

M-81		M-64		M1A1	
Height (ft)	Casualties	Height (ft)	Casualties	Height (ft)	Casualties
		6-in. shielding (5° to 14°)			
Contact	1.5	Contact	3	Contact	1.2
16	25	19	31		
30	28	30	42		
50	28	50	42		
70	25	70	31		
		0-in. shielding (0°)			
Contact	11	Contact	13	Contact	12.5
16	55	19	73		
30	55	30	82		
50	53	50	75		
70	48	70	55		

To summarize the results of this test, 12-in. shielding gave superiority for the air-burst M-64 over contact-burst of 20 to 1; 6-in. shielding gave about the same; and 0-in. shielding gave about 5 to 1. For the M-81 air burst compared to equivalent loads of 2 clusters (M1A1, contact), the superiority factor is 12 to 1 for 6-in. and 12-in. shielding, and is 2 to 1 for 0-in. shielding. Note that between 20 and 70 ft, there is little variation of damage versus height of burst. The optimum height occurs at about 35 ft for both bombs. Actually, the optimum height depends somewhat on the size of the target. To illustrate, if the target area is considered to contain one man prone in each trench, the foregoing figures hold; if the target area is considered to contain three men crouching in each trench, the same number of casualties will result for the higher bursts but relatively more casualties for the lower bursts. Hence the optimum burst height is reduced. It is interesting to note that the theoretical calculation of Morse and Transue in Ordnance Dept. TDBS Report No. 41 when corrected for target density agrees exceedingly well with the Eglin Field results for the M-64 bomb.

A point to consider here concerning evaluation of effectiveness is that nose initiation of the bomb explosion does not yield the best fragmentation pattern for such anti-personnel work. For the M-64 bomb, the side spray when fired statically is 10° behind the normal to the bomb axis. The bomb striking velocity tends to bring the fragments back to 0° but this is not enough. With tail initiation there would be a downward spray of the fragments that would cause more casualties against shielded personnel. Computations show that this increase should amount to a factor of 2 to 3.

Another test of the fragmentation effects against shielded personnel was made at Ashley Walk, England. This was conducted with 500-lb bombs fuzed with T50 fuzes released from 10000-ft altitudes at 200 mi/hr against a target consisting of 200 slit trenches. Each trench was 6 × 2 × 1 ft, containing a flat wooden target board 3 ft 10 in. × 1 ft 3 in. × $\frac{1}{2}$ in., which was considered to be the area presented to fragments coming from any direction by three men crouching in a deeper trench. The differences between this setup and Eglin Field are that the trenches were near the center of the effect field, were 30 ft apart instead of 15, were piled up on only one side with dirt instead of all around, and were composed of much harder soil than the sandy soil in Florida. The results reported are these: the advantage of a 10-ft air burst over a contact burst is 5 to 1, and the advantage of a 35-ft air burst over a contact burst is 10 to 1. In an official report on this test, the British Ordnance Board included in its evaluation of effectiveness the effect of blast for the surface burst, which yielded as the ratio of air burst to ground burst the figures given in Table IV. Some quotations from the report

Table IV. Ratio of effectiveness of air burst to ground burst in English tests. The effect of blast for the ground burst was considered.

Height of Burst (ft)	Men in Deep Trenches	Men in Shallow Ditches	Men Prone (no cover)	Mech. Transport
10	4.0	3.7	1.3	1.0
35	3.7	5.3	1.2	0.4

might be of interest. They say that there is no case for air bursts against men in the open on level ground but as soon as the ground becomes uneven the surface-burst bomb is at a disadvantage. If the unevenness increases, the target will eventually become that of a man lying in a shallow hole or ditch and should be considered as equivalent to men in shallow ditches. (See Table IV for the advantage of air burst.)

A test of the fragmentation effect of VT-fuzed rockets versus that of M4 superquick-fuzed rockets was made at Fort Bragg. The effect field contained 1 × 6-ft boards (1 in. thick) spaced 5 yd apart in checkerboard array, with 1-in. shielding. For each round that burst on the effect field, the boards hit by at least one fragment that penetrated at least $\frac{1}{4}$ in. into the wood were counted. The results (Table V) indicate that air bursts obtained with T6 fuzes are 5 times as effective as ground-impact bursts against slightly shielded personnel.

Table V. Comparison of effectiveness of bombs fuzed with VT fuzes and with M4 superquick fuzes.

Fuze	Number of Rounds	Height of Burst (ft)	Number of Targets Hit per Round
M4 Superquick	20	—	4
T6	20	60	21

(b) Distribution of incendiary material. — VT fuzes are useful on the 165-gal belly tank and on the M10 spray tank filled with napalm-gasoline-gel.

When released from high altitudes, about 50% of the incendiary material in any contact-fuzed vehicle is left in the bomb crater. To avoid this, an air burst of the right height combined with a burster of the right strength was needed.

In tests under standard release conditions of the T51 fuze on the 165-gal belly tank (the tank having been modified to take the T51 fuze and an M13 Tetryl burster and M9 white phosphorus igniter) the results were 40- to 60-ft burst heights with very little crater, and fire areas of about 15000 to 20000 ft^2. With two tanks per fighter plane, an area of about 35000 ft^2 is covered, assuming no overlap in salvo. The standard of comparison in this test was the 165-gal tank provided with an "all-way" igniter and released from a fighter at about a 50-ft altitude, which gave an elongated fire area (250 × 80 ft) of about 20000 to 25000 ft^2. Hence we get very nearly as good fire area with VT-fuzed tanks dropped from high altitudes as with the standard of comparison from low altitudes.

In tests of the 33-gal M10 spray tank, the tanks as modified for the tests did not have good ballistic properties. When used with T50E4 fuzes and M13 bursters, however, they gave 5- to 10-ft burst heights, very small craters, and a good fire area considering the rather small amount of incendiary material in the tank. A fire area of about 2500 ft^2 is obtained per tank. B17 and B24 bombers can carry about 12 such tanks, giving a total fire area of about 30000 ft^2 per bomber.

(c) <u>Distribution of nonpersistent gas.</u> — Another application of the fuzes which I have mentioned is the distribution of nonpersistent gas. We have some preliminary results of testing done at Porton, England, in which gas-filled 500-lb LC bombs were burst at 50 ft above the ground. The average area of heavy contamination was approximately 36000 ft^2, which is about four times the area obtained by surface-burst bombs containing the same gas, and about seven times the lethal area of an air-burst M64 against shielded targets.

A test of the use of nonpersistent gas against a mock-up of a Japanese battleship was made in Panama recently. I understand that you may be shown a motion picture of it, so I will pass over the subject. It is a very effective picture of some 84 1000-lb bombs filled with nonpersistent gas dropped on the target from 15000 ft. Of the 84 bombs, I believe 71 were proper functions. The bombing was exceedingly precise so that the gas completely enveloped the target.

(d) Enhanced blast effect. -- The next application of air burst to be considered is the enhanced blast effect obtained by an air burst of a very large bomb, for example, the 4000-lb bomb. I quote here from a report from Dr. Astin: "Estimates of the enhancement of blast effect by air burst in HC bombs have been made by Dr. Christopherson of M.E.S. and by Dr. Wilson of OSRD in America. The former, in an analysis of the damage wrought by nine air-burst fly-bombs, predicts an optimum height of burst for the 4000-lb bomb of 30 ft and an enhancement of the area of damage of 50% to 70% against blast-susceptible targets. As a result of extensive static trials in America, Dr. Wilson predicts an optimum height of burst for the 4000-lb bomb of 70 ft and a 100% increase in the area of damage. The optimum height is apparently not critical, so that heights between 30 ft and 70 ft would be satisfactory."

(e) Mine clearance. -- On mine clearance, some tests were made by the Engineer Board, first with static rounds using the German tellermine model and different burst heights and then by actually dropping some bombs with T50 fuzes on them and measuring the effect. I have a brief summary of it here. According to the results of the tests, air burst can be used to advantage for the clearance of mines that are susceptible to blast effect. Although there is no appreciable increase in the area of clearance with air burst, it has the following advantages: (a) no cratering; (b) increased reliability of clearance particularly with respect to the uniformity of the area cleared (the contact burst gave a rather irregular path of clearance whereas the air burst always cleared quite a uniform path); (c) disclosure of the mine-field pattern owing to the absence of cratering; (d) less variation of performance with the depth of mine burial.

(f) Anti-aircraft. -- The anti-aircraft application is one that has proven most effective. There is no doubt that the air burst is a real tool here, whether for ground-to-air or for air-to-air use. Concerning the latter, an unofficial report of a study by the AAF Board shows the potential improvement of VT fuzes over ordinary fuzes to be about 20 to 1. Although the bomb

VT fuzes are not at present of optimum design for air-to-air bombing, rocket VT fuzes have been studied extensively and have shown considerable advantage over ordinary fuzes.

Estimates were made of the probability of damaging aircraft in the air as follows. By bursting shells in the neighborhood of aircraft parked on the ground, the probability of damage was determined for all positions of burst. Combining these data with data on the probability of bursting fuzes at certain distances from the plane, and assuming certain dispersion and air-to-air firing data, estimates of the probability of damage in aerial combat were arrived at.

The most reliable estimates of the probability of destroying enemy aircraft using T5 fuzes on $4\frac{1}{2}$-in. (M8A3) Army rockets show that in firing at a twin-engine bomber from 1000 yd astern, each round fired has about one chance in ten of damaging the enemy plane sufficiently to prevent it from returning to its base if it cannot return on one engine, and about one chance in sixteen if it can return on one engine. Using the same assumed value of rocket dispersion, the chance of a direct hit would be about one in a hundred.

(g) Miscellaneous. -- The following extracts from the minutes of the 14th meeting on September 21, 1944, of the Aircraft Anti-Ship Committee contain recommendations on the applicability of VT fuzes for attacks against E and R boats, merchant ships, and trawlers. The Coastal Command are of the opinion that, considering the difficulties of stick bombing by night, the air burst is unquestionably the most suitable form of fuzing. A direct hit offers an equal chance of sinking, and in the case of a near miss the chance of causing serious damage is very much greater. To substantiate this, Air Vice Marshall Ellwood quoted details of a prisoner-of-war report and also results of the mistaken attack on H.M.S. Melbreak.

4. Limitations

Now we come to the limitations of the fuze. There are two things that I would really like to see improved in the fuze if we could do it. You noticed in the performance figures I quoted that we can expect, to be conservative, 80% proper functions, 15 or 16% early functions, and 4% duds. Duds are

[redacted]

inexcusable even at a 4% level because it is easy to get rid of duds in manufacture, but it is very difficult to get rid of early functions. Furthermore, the tail inertia fuze used on bombs carrying VT nose fuzes will explode the bomb in case of duds.

Conditions producing malfunctions and methods of minimizing them are listed in TB 9X 106. Malfunctions can arise from (a) faulty construction of the fuze, (b) faulty construction of the vehicle, (c) faulty assembly, (d) improper bomb or rocket selection, (e) insufficient intervalometer spacing, (f) rain, (g) too high or too low altitude of release, and (h) insufficient plane speed.

Concerning mutual interaction of fuzes, fortunately the property of the fuze that requires motion of the reflector permits two neighboring projectiles to come relatively close to one another without undue effect, because of their low relative velocity. Field tests have shown that electrical interaction between fuzes properly designed is quite small, and that most of the trouble is encountered when one projectile explodes within the sphere of action of another. This places certain limitations on the spacing allowable between vehicles. Extensive tests at Aberdeen Proving Ground show that the number of early functions for train bombing is essentially the same as for individual releases if the train spacing is equal to or greater than 50 ft for the M81 and 100 ft for the M64. Tests of rockets fired in salvo with 1/10-sec spacing indicated no mutual interaction.

No maximum altitude of release is specified for VT fuzes other than the T91 and T92. However, because of decreased vibration and bearing wear, releases at lower altitudes may be expected to yield fewer early functions than releases at higher altitudes. The use of an arming delay will reduce malfunctions for high-altitude releases to some extent because of reduction in the time during which the fuze falls armed.

To summarize, it has been shown by means of effect-field tests, that VT fuzes now in production are more effective than contact fuzes by a ratio ranging from 2-to-1 to 20-to-1 in a number of important applications. The VT fuze is a new weapon, and the possibilities of advantageous applications have by no means been thoroughly explored.

[redacted]