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RESEARCH AND DEVELOPMENT OF MATERIEL

ENGINEERING DESIGN HANDBOOK

AMMUNITION SERIES

FUZES, PROXIMITY, ELECTRICAL

PART TWO (U)

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AMCP 706-212(S), Fuzes, Proximity, Electrical, Part Two (U), forming part of the Ammunition Series of the Army Materiel Command Engineering Design Handbook Series, is published for the information and guidance of all concerned.

(AMCRD)

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FOREWORD

The Ammunition Series is part of a group of handbooks covering the engineering principles and fundamental data needed in the development of Army materiel, which (as a group) constitutes the Engineering Design Handbook Series.

Fuzes, Proximity, Electrical comprises five numbered Parts, each of which is published as a separate volume and assigned an Army Materiel Command Pamphlet (AMCP) number. Arrangement into Parts and Chapters, with Chapter titles, is as follows:

AMCP 706-211(C), *Fuzes, Proximity, Electrical—Part One (U)*

Chapter 1 —Introduction
Chapter 2 —Philosophy of Fuze Design
Glossary
Index

AMCP 706-212(S), *Fuzes, Proximity, Electrical—Part Two (U)*

Chapter 3 —VHF and UHF Radio Systems

AMCP 706-213(S), *Fuzes, Proximity, Electrical—Part Three (U)*

Chapter 4 —Microwave Radio Systems

AMCP 706-214(S), *Fuzes, Proximity, Electrical—Part Four (U)*

Chapter 5 —Nonradio Systems
Chapter 6 —Multiple Fuzing

AMCP 706-215(C), *Fuzes, Proximity, Electrical—Part Five (U)*

Chapter 7 —Power Supplies
Chapter 8 —Safety and Arming Devices
Chapter 9 —Components
Chapter 10—Materials
Chapter 11—Construction Techniques
Chapter 12—Industrial Engineering
Chapter 13—Testing

The purpose of these handbooks is twofold: (1) to provide basic design data for the experienced fuze designer, and (2) to acquaint new engineers in the fuze field with the basic principles and techniques of modern fuze design.

These handbooks present fundamental operating principles and design considerations for electrical fuzes and their components, with particular emphasis on proximity fuzes. Information on mechanical fuzes, and other general information on fuzes, is contained in ORDP 20-210, *Fuzes, General and Mechanical.*

As indicated by the Table of Contents, the arrangement of material is primarily topical. This permits ready reference to the area in which the user desires information.

Some subjects are covered in considerable detail, whereas others are covered only superficially. Generally, the amount of coverage is an indication of the state of development of a system. There are exceptions to this, however. For example, although the section on optical fuzing is comparatively extensive, this type of fuzing is not as far advanced as other methods of fuzing. Much of the information in this section, however, is based on an unpublished report. Rather than risk the loss of this information, and to disseminate it more widely, the information is included in these handbooks.

A Glossary is included in which terms that are unique to the fuze field, or that have special meaning in the fuze field, are defined.

References at the end of a chapter indicate the documents on which the chapter is based. They also furnish additional sources of information.

Titles and identifying numbers of specifications, standards, regulations and other official publications are given for the purpose of informing the user of the existence of these documents, however, he should make certain that he obtains editions that are current at the time of use.

Defense classifications are indicated for chapters, paragraphs, illustrations and tables. The degree of classification of the contents of each illustration or table is indicated by the appropriate initial symbol immediately preceding the title. In the case of classified illustrations or tables the classification of the title itself is indicated by appropriate initial symbol immediately after such title.

These handbooks were prepared under the joint direction of the Harry Diamond Laboratories (formerly Diamond Ordnance Fuze Laboratories) and the Engineering Handbook Office, Duke University. Text material was prepared by Training Materials & Information Services, McGraw-Hill Book Company, Inc., under contracts with both of these organizations. Material for text and illustrations was made available through the cooperation of personnel of the Harry Diamond Laboratories. The operation of the Engineering Handbook Office of Duke University is by prime contract with the U. S. Army Research Office, Durham.

Comments on these handbooks should be addressed to Commanding Officer, Army Research Office, Durham, Box CM, Duke Station, Durham, N. C.

PREFACE

Part Two of this handbook, consisting of Chapter 3, covers the basic principles and design considerations for radio proximity fuzes operating in the VHF and UHF bands. A Table of Contents for all Parts is also included. The Index and a Glossary, defining terms that are unique to, or that have special meaning in, the fuze field are included in Part One. Fuzing systems considered in this volume include continuous-wave Doppler, pulsed Doppler, frequency-modulated, pulsed frequency-modulated, radio induction field, capacity, and pulsed radar.

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CHAPTER 3

(S) VHF AND UHF RADIO SYSTEMS

3-1 (S) CW DOPPLER FUZING

(U) The CW Doppler fuze was developed early in World War II. It still has many advantages over later radio-type proximity fuzes, particularly in simplicity, cost, and construction ease. Although it was the first radio-type proximity fuze developed, it is still considered satisfactory, with only minor refinements, for many present-day fuzing applications. This is especially true in mortar, bomb, and artillery fuzing where very high reliability and accuracy are normally not specified.

This section of the handbook presents the basic principles of the CW Doppler fuze, and briefly discusses some of its design considerations. Reference 1 gives a detailed analysis of operation and design of the CW Doppler fuze.

3-1.1 (U) BASIC OPERATION

The intelligence system of a CW Doppler proximity fuze (Figure 3-1) consists of an antenna, an oscillator-detector, a Doppler amplifier, and a firing circuit. The oscillator-detector generates an RF signal, which is coupled to the antenna and radiated into space. If the radiated signal strikes a target, a small portion of the signal is reflected back to the antenna. The time required for the signal to travel to the target and back results in a phase difference between transmitted and reflected wave. As the distance between the fuze and target decreases, the relative phase between the radiated and reflected signal changes and appears as a change in frequency of the reflected signal. The difference in frequency between the radiated signal and received signal, because of relative motion between the target and fuze, is called the difference frequency or Doppler frequency (Ref. 2). For a typical fuze design, the difference or Doppler frequency is in the audio frequency range and of the order of a few hundred cycles per second.

The Doppler signal is detected by the oscillator-detector, and coupled to the input of the Doppler amplifier. Amplification is required because the detected signal is of the order of a fraction of a volt. The output of the Doppler amplifier is applied to the firing circuit, which consists essentially of a thyratron, a detonator, and a capacitor in series. When the output of the amplifier exceeds a predetermined level, the capacitor discharges through the thyratron to trigger the detonator.

Because detonation occurs when the output of the amplifier reaches a predetermined level, the distance from the target at which detonation occurs can be controlled. For a given orientation of the fuze and target, the detector signal amplitude is a function of the distance between the fuze and target. Therefore, the distance of operation can be set properly by setting the amplifier gain and the thyratron holding bias.

3-1.2 (U) BASIC PARAMETERS

3-1.2.1 (U) Doppler Shift and Radiation Resistance (Ref. 3)

The effect of radiation from a target may be considered in two ways: the Doppler frequency concept or the radiation resistance concept. The radiation resistance concept is more commonly used because it lends itself more readily to mathematical treatment.

The Doppler frequency concept may be considered in the following manner (Ref. 4): because the fuze moves toward the target, the frequency of radiation striking the target is slightly higher than that emitted by the fuze by an amount V/λ; where V is the relative

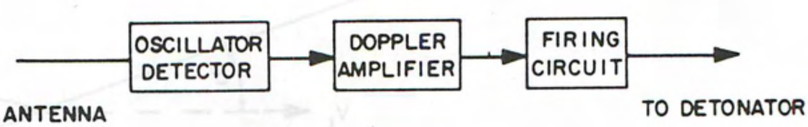

Figure 3-1 (U). Block Diagram of Basic CW Doppler Fuze

velocity of the fuze and target, and λ is the wavelength of the radiated wave. Similarly, the wave reflected back to the fuze from the target is higher than that at the target by an amount V/λ. Therefore, the reflected radiation returns to the fuze with a higher frequency than that of the fuze oscillator by an amount $2V/\lambda$, which is the Doppler frequency. The frequency of the reflected signal, f', as seen by the fuze is

$$f' = f + \frac{2V}{\lambda}$$

where

f = fuze oscillator frequency

$\frac{2V}{\lambda}$ = Doppler frequency

The closing velocity between the fuze and target, and not simply the velocity of the fuze, determines the Doppler frequency output of the oscillator detector. Therefore, in the case of the ground target approach (Figure 3-2), the Doppler frequency is modified and becomes

$$f_d = \frac{2v \sin\theta}{\lambda} \qquad (3\text{-}1)$$

where

θ = fuze angle of approach with respect to earth

$V \sin\theta$ = closing velocity of fuze with respect to earth

In Figure 3-3, the air target case, both target and fuze are traveling in the same direction. This is a typical encounter between a target and an air-to-air rocket. The Doppler frequency is modified to become

$$f_d = \frac{2(V_1 - V_2)\cos\theta}{\lambda} \qquad (3\text{-}2)$$

where

V_1 = fuze velocity

V_2 = target velocity

θ = angle between fuze trajectory and line connecting fuze and target

$(V_1 - V_2)\cos\theta$ = closing velocity of fuze with respect to target

As stated above, the radiation resistance concept is usually used because it lends itself more readily to mathematical treatment. In this analysis, the current, I (Figure 3-4), produced in the fuze antenna by the oscillator is considered. This current sets up radiation and dissipates energy into space as if the antenna had a resistance, R_A, called the radiation resistance. In the presence of a target, the antenna current differs from I by the amount induced by the reflected wave. The incremental

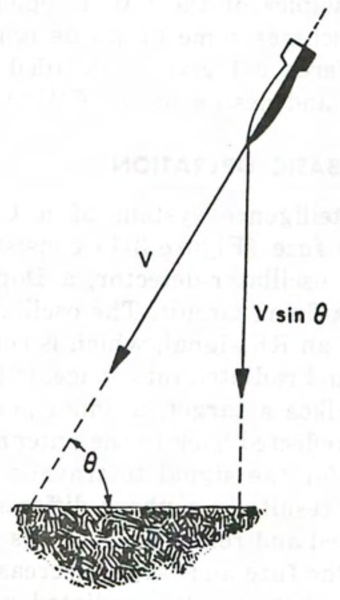

Figure 3-2 (U). Determining Doppler Frequency for Ground Approach Case

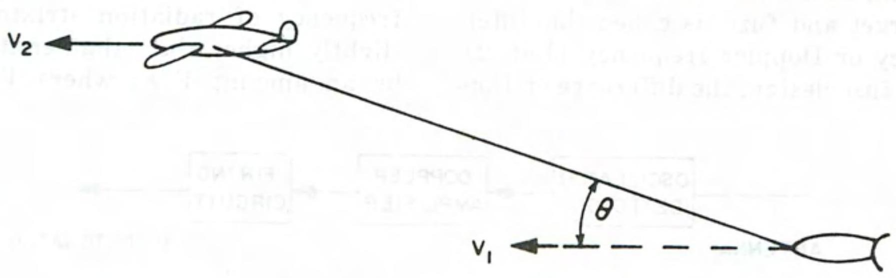

Figure 3-3 (U). Determining Doppler Frequency for Air Target Case

current I' shown in Figure 3-4 is proportional to I but not necessarily in phase with I. The resultant current in the antenna is the vector sum of I and I'. When there is relative motion between the fuze antenna and the target, however, vector I' rotates as indicated by the dotted line, and phase angle, ϕ, varies with time in a cyclic fashion. This causes modulation of the antenna current amplitude, which can be considered as produced by modulation of radiation resistance, R_A. Equations 3-1 and 3-2 define the frequency of this modulation.

The amplitude of the variation in radiation resistance depends on the radiation pattern of the fuze, the distance from the fuze to the target, and the reflection properties of the target. For the ground target case, the variation can be calculated as follows

$$\frac{\Delta R_A}{R_A} = \frac{G}{4\pi}\frac{\lambda}{h}\, nf^2(\theta) \qquad (3\text{-}3)$$

where

$\frac{\Delta R_A}{R_A}$ = fractional change in fuze antenna radiation resistance

G = fuze antenna gain figure

h = height above ground target

n = reflection coefficient of ground

$f^2(\theta)$ = antenna radiation pattern function

3-1.2.2 (U) Sensitivity

The circuits used to detect changes in antenna radiation resistance must be very sensitive because ΔR_A is usually only a very small fraction of R_A, about 0.01 to 0.001 for heights ranging from 10 to 100 ft. For higher heights, ΔR_A becomes so small that the signal approaches noise level. Therefore, function heights for radio Doppler fuzes are usually limited to a few hundred feet unless special techniques are used.

The sensitivity of an oscillator-detector is defined as

$$S = \frac{\Delta E}{\Delta R_A / R_A} \qquad (3\text{-}4)$$

where

S = sensitivity

ΔE = change in detector output voltage produced by the fractional change in radiation resistance, R_A

Figure 3-4 (U). Vector Diagram for Changes in Antenna Current

3-1.2.3 (U) Doppler Signal Amplitude

By combining Equations 3-3 and 3-4, the amplitude of the Doppler signal may be defined as

$$\Delta E = \frac{SG\lambda nf^2(\theta)}{4\pi h} \qquad (3\text{-}5)$$

This equation indicates that the amplitude of the Doppler signal increases in inverse proportion to the distance between the fuze and target.

3-1.2.4 (U) M Wave (Ref. 4)

The signal produced as the fuze approaches the target is called the M wave. A plot of an M wave for a typical ground approach is shown in Figure 3-5. The frequency of the wave is defined by Equation 3-1 and the amplitude by Equation 3-5. The amplitude of the signal changes rapidly because the velocity of the fuze is high. The frequency, however, changes rather slowly. As the fuze falls through the last few hundred feet of flight, its velocity and, therefore, the frequency of the signal are essentially constant. The amplitude of this signal determines fuze burst height for the ground approach case. Therefore, the characteristics of the Doppler amplifier, particularly steady-state amplification, are major considerations in determining fuze burst height (see paragraph 3-1.5.1).

A typical M wave for the air target case is shown in Figure 3-6. In contrast with the

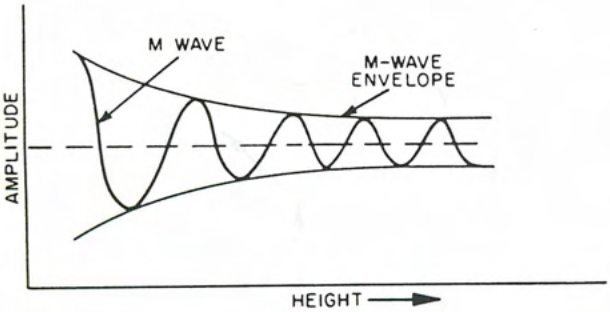

Figure 3-5 (U). M Wave for Ground Approach Case

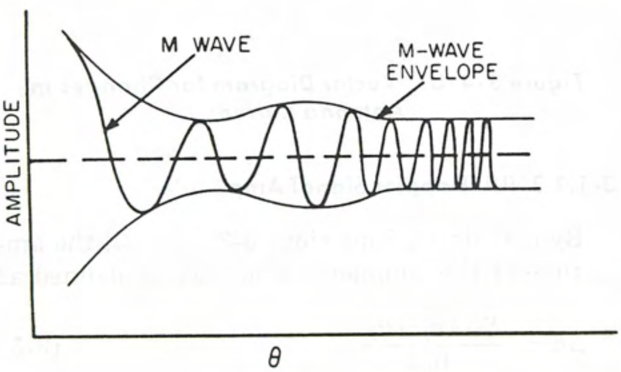

Figure 3-6 (U). M Wave for Air Target Case

ground target case, the frequency of the Doppler signal decreases rapidly as the fuze approaches the target. This decrease is a result of the rapid change in θ (Equation 3-2) as the fuze moves along its trajectory. For ground targets, θ (Equation 3-1) remains essentially constant during the last few hundred feet of fuze trajectory. Both the frequency and the amplitude of the signal are used to control burst position for the air target fuze, and amplifier shaping as well as amplifier gain must be considered (see paragraph 3-1.5.4).

3-1.3 (S) ANTENNA SYSTEMS

(U) The fuze designer must understand the various properties of antennas to select the correct one for the intended fuzing application. Detailed discussions of antennas, except loop antennas, are presented in References 1 and 4. Loop antennas, are discussed in the following paragraphs.

3-1.3.1 (U) Loop Antennas (Ref. 5)

The loop antenna used for fuze application is part of the oscillator tank circuit. It was developed primarily to make the fuze action and performance substantially independent of the missile on which the fuze is mounted. This permits the same fuze design to be used in fuzing a variety of similar missiles. Also, loop antennas allow fuze operation during rocket engine burning.

Other types of antennas using the missile structure itself as an antenna are influenced by the ionized gases from the rocket motor. These gases, in effect, change the electrical length of the missile and, consequently, its radiation pattern. The physical requirements imposed on fuze design make it desirable to include the fuze transmitting and receiving antennas as integral parts of the fuze assembly itself.

The loop antenna is essentially a wide copper strip or cylinder with a distributed capacitance mechanically integral with it. The relatively small physical size of the antennas results in an inefficient radiation system, and introduces special circuit problems. These problems relate to obtaining satisfactory sensitivity, power output, and other characteristics.

Because the loop antenna is the oscillator tank and, conversely, the tank circuit forms the antenna, compromises are required in the overall design. The closeness of the one-turn tank to other fuze parts results in considerable loss of RF power. Special demands are placed on the oscillator tube to supply the high current requirements of the tank-loop for adequate power output.

Basically, there are two types of loop antennas; transverse and longitudinal. In transverse loops, the plane of the loop is perpendicular to the axis of the missile body, in longitudinal loops, the plane of the loop is parallel to the axis of the missile body. The following paragraphs discuss general characteristics of transverse and longitudinal loop antennas.

3-1.3.2 (U) Characteristics of All Loop Antennas

Loop antenna radiation is produced by:

(1) Loop excitation

(2) Dipole excitation

(3) Longitudinal excitation from the projectile body.

Loop excitation (1) is desirable; (2) and (3), undesirable.

Loop excitation produces an almost symmetrical pattern with zero field strength along the axis passing through the center of the loop and a maximum field strength approximately on a circle in the plane of the loop.

Dipole excitation is produced by the loop that simulates a small dipole with elements in the plane of the loop between the points of maximum RF voltage difference. Dipole radiation can be eliminated by using a push-pull oscillator. In this case, two dipoles oppositely excited are produced. These are close enough for their radiations to cancel. With loops of more than one turn, stronger dipole radiations are produced.

Longitudinal excitation from the projectile body is always present to some extent because of stray capacity between the high potential parts of the oscillator and the body. Longitudinal excitation is reduced by grounding the oscillator circuits at, or near, the center of the loop. This balances out the effects of the coupling between the front end of the projectile body and the two high potential points of opposite phase on the oscillator. Probably the most convenient method of doing this is to adjust the capacity at one end of the loop. It can also be done by moving the grounding point on the loop but the balance adjustment is very critical.

Figures 3-7 through 3-10 show how the three sources of radiation combine for various orientations of projectile and pickup antennas. In the figures, constant signals and varying signals from the particular source of radiation being considered are denoted by *c* and *v*, respectively. Where one source of radiation was much

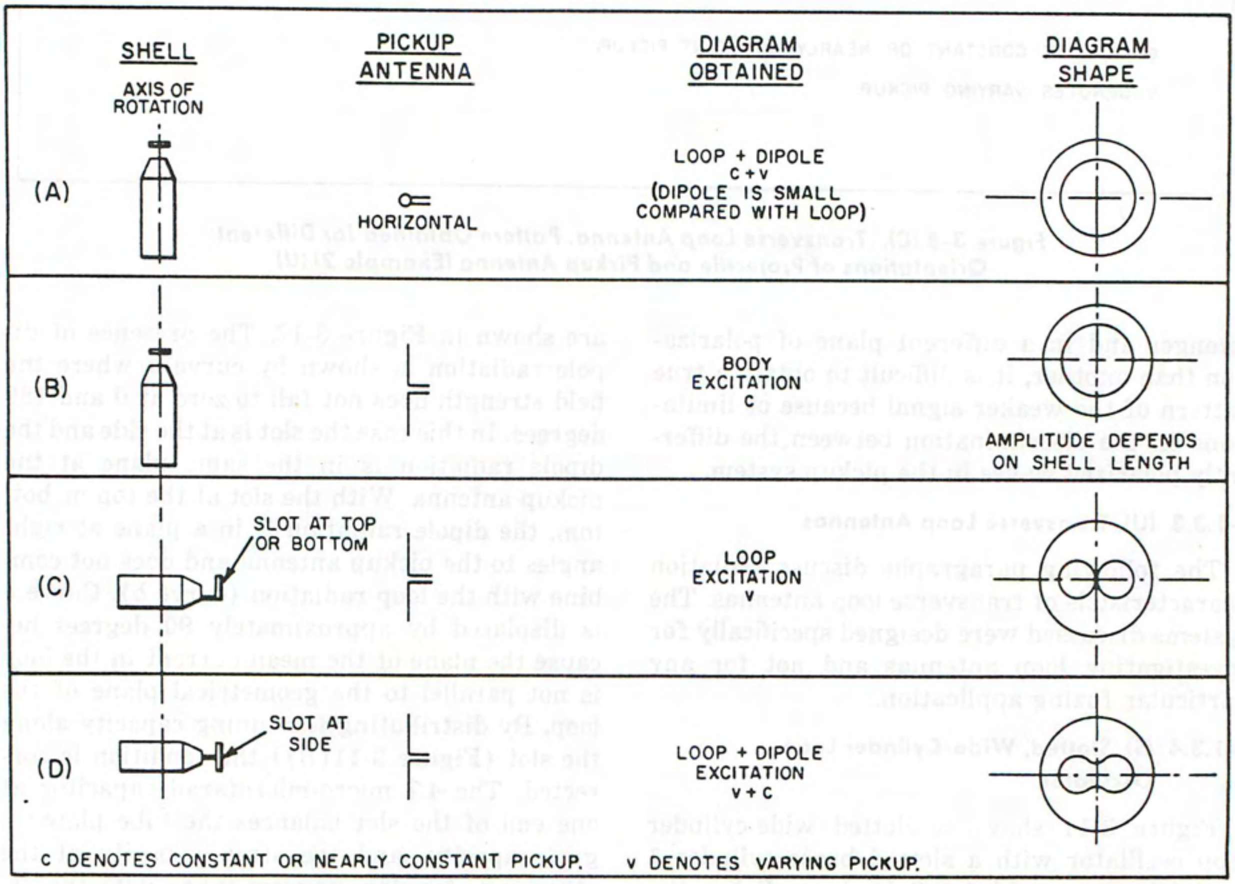

Figure 3-7 (C). Transverse Loop Antenna. Pattern Obtained for Different Orientations of Projectile and Pickup Antenna (Example 1) (U)

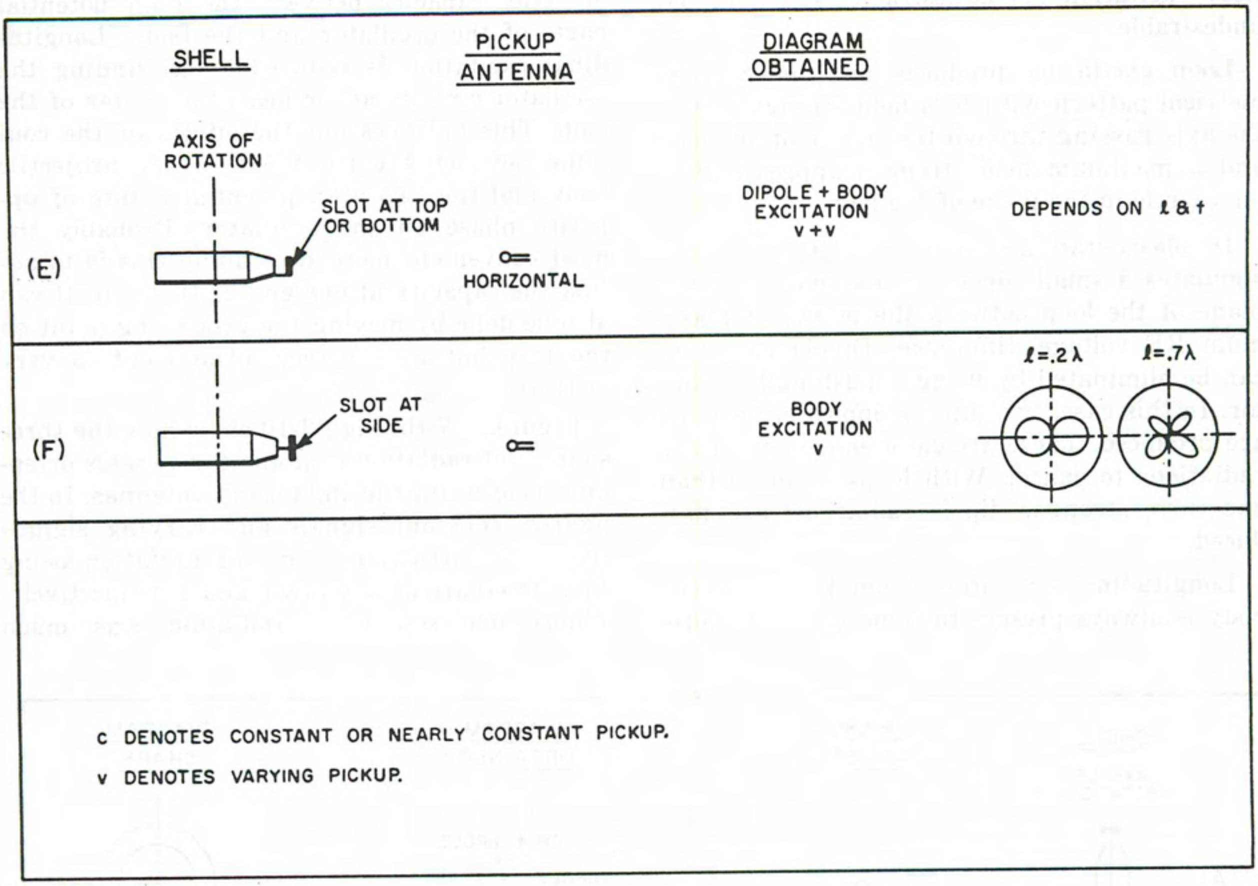

Figure 3-8 (C). Transverse Loop Antenna. Pattern Obtained for Different Orientations of Projectile and Pickup Antenna (Example 2) (U)

stronger and in a different plane of polarization than another, it is difficult to obtain a true pattern of the weaker signal because of limitations on the discrimination between the differently polarized waves in the pickup system.

3-1.3.3 (U) Transverse Loop Antennas

The following paragraphs discuss radiation characteristcis of transverse loop antennas. The systems discussed were designed specifically for investigating loop antennas and not for any particular fuzing application.

3-1.3.4 (S) Slotted, Wide-Cylinder Loop Oscillator

Figure 3-11 shows a slotted wide-cylinder loop oscillator with a slotted brass cylinder 1 in. in diameter and 1-1/2 in. long. Polar diagrams for the system, obtained by using the arrangements shown in Figure 3-7(C) and (D), are shown in Figure 3-12. The presence of dipole radiation is shown by curve *a* where the field strength does not fall to zero at 0 and 180 degrees. In this case the slot is at the side and the dipole radiation is in the same plane at the pickup antenna. With the slot at the top or bottom, the dipole radiation is in a plane at right angles to the pickup antenna and does not combine with the loop radiation (curve *b*). Curve *a* is displaced by approximately 90 degrees because the plane of the mean current in the loop is not parallel to the geometrical plane of the loop. By distributing the tuning capacity along the slot (Figure 3-11(B)) the condition is corrected. The 4.7 micro-microfarad capacitor at one end of the slot balances the tube plate-to-grid capacity, and the stray capacity at the other end. A polar diagram taken with the arrangement shown in Figure 3-7(A) produces a circle within 0.5 db. The strongest field is obtained when the slot in the loop is towards the pickup antenna. Zero field strength is obtained for the arrangement in Figure 3-7(B).

As the spacing between the bottom of the loop and the body (Figure 3-11(B)) is varied, the radiated field strength changes (Figure 3-13). As the loop is brought closer to the body, radiation is reduced but the angle of maximum radiation remains approximately the same.

3-1.3.5 (S) Push-Pull Loop Oscillator

Figure 3-14 shows a push-pull loop oscillator with a loop 2 in. in diameter and 3/4 in. wide, and two opposite slots. Polar diagrams indicate that the radiation pattern is essentially the same for any position of the slots. The diagrams show zero radiation at 0 and 180 degrees, indicating an absence of dipole radiation. A typical polar diagram for this type of antenna is shown in Figure 3-15.

3-1.3.6 (S) Slotted, Narrow-Cylinder Loop Oscillator

Figure 3-16 shows a slotted, narrow-cylinder loop oscillator in which the spacing between the loop and body can be easily varied. It is basically a loop 2 in. in diameter and 3/4 in. wide, and is supported from the midpoint opposite the slot by a tube through which the power suply leads run. Plate and grid blocking capacitors are provided by foils placed against the loop, and insulated from it by a mica sheet. Direct current connections to the loop are made at the point of zero RF voltage. Polar diagrams for several different spacings (Figure 3-17) show that the radiation angle is similar for all spacings, although the field strength varies.

The effect of a large ground plane can be seen by placing an aluminum disc behind the loop. Figures 3-18 and 3-19 show how the angle of

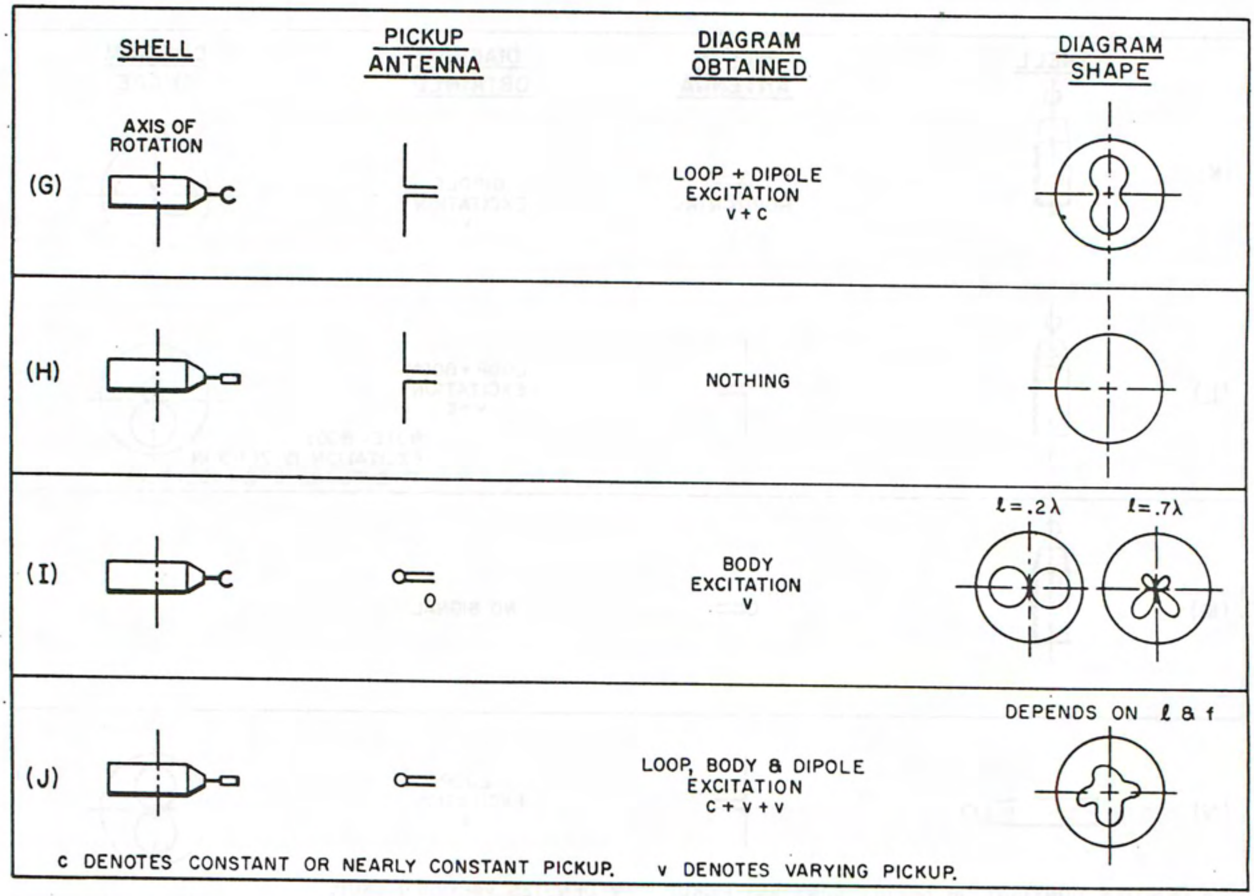

Figure 3-9 (C). Longitudinal Loop Antenna. Pattern Obtained for Different Orientations of Projectile and Pickup Antenna (Example 1) (U)

maximum radiation increases as the disc diameter decreases. The effect of placing a flat-ended cylinder 24-1/2 in. long and 12 in. in diameter behind the loop is shown in Figure 3-20. The pattern is similar to the one for a 12-in. disc shown in Figure 3-18.

3-1.3.7 (S) Wire Loop Oscillator

An oscillator made with a loop of #14 copper wire is shown in Figure 3-21. By making the position of the loop adjustable, the effects of spacing between the loop and the body can be shown. These effects are plotted in Figure 3-22 and show that the radiation angle is independent of the spacing.

3-1.3.8 (S) Small-Diameter, Narrow-Cylinder Loop Oscillator

Figure 3-23 shows an oscillator with dimensions more suitable for use in a fuze. It uses a brass cylinder, 1-1/4 in. in diameter and 1/2 in. wide, as the tank. In a test-model, longitudinal excitation of the projectile body was reduced to a low level by the method described in paragraph 3-1.3.2. The radiation pattern is shown in Figure 3-24. There is a marked similarity in the radiation pattern between this and the previous loops discussed.

3-1.3.9 (S) Longitudinal Loop Antennas

Figure 3-25 shows an oscillator used to determine the radiation pattern of a longitudinal loop antenna. The oscillator is basically a one-turn wire tank with a diameter of 1-3/4 in. The entire oscillator is supported from the front end of the test model by a plastic tube. Radiation patterns for various arrangements of the test model and pickup antenna (Figures 3-9 and 3-10) are shown in Figures 3-26

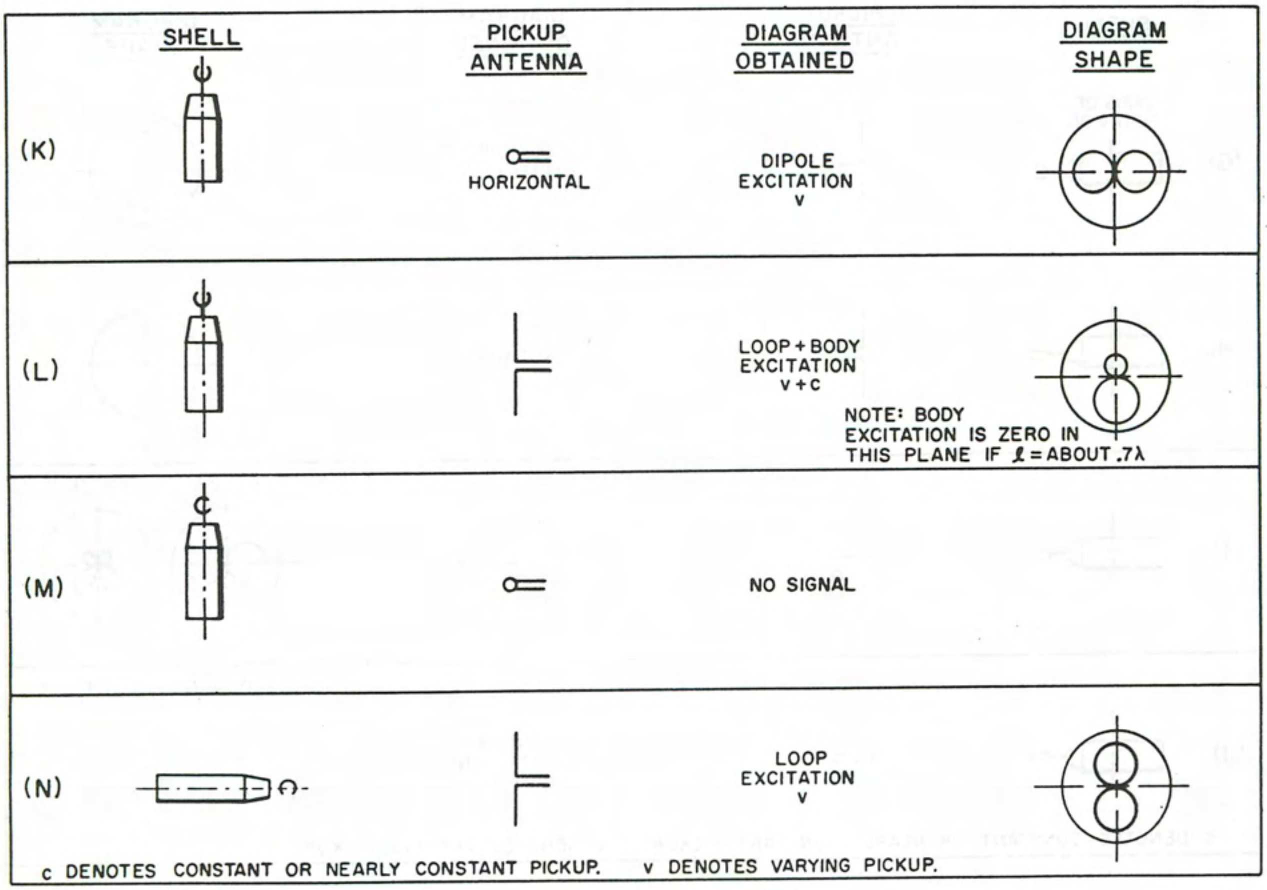

Figure 3-10 (C). Longitudinal Loop Antenna. Pattern Obtained for Different Orientations of Projectile and Pickup Antenna (Example 2) (U)

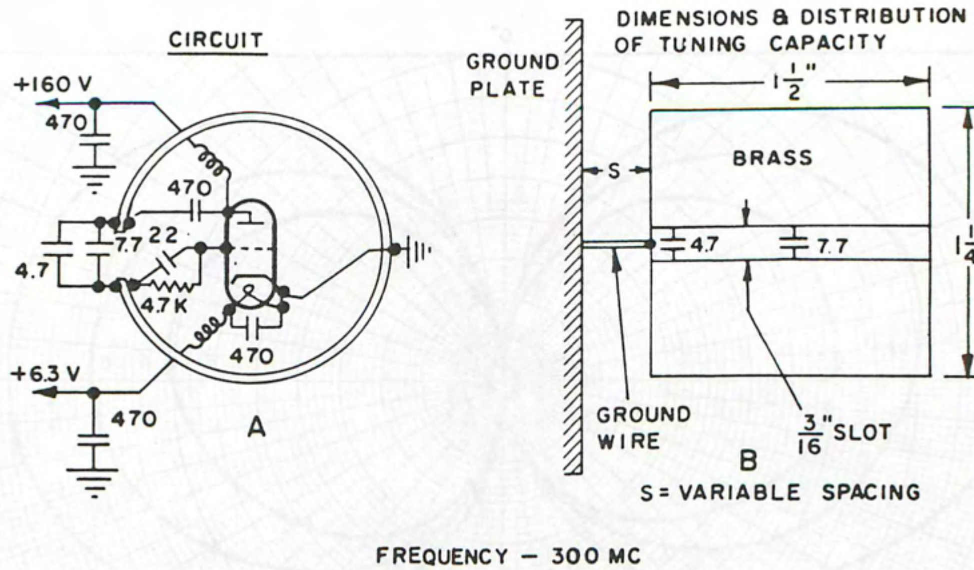

Figure 3-11 (S). Transverse Loop Oscillator with Wide Cylinder Resonant Circuit (U)

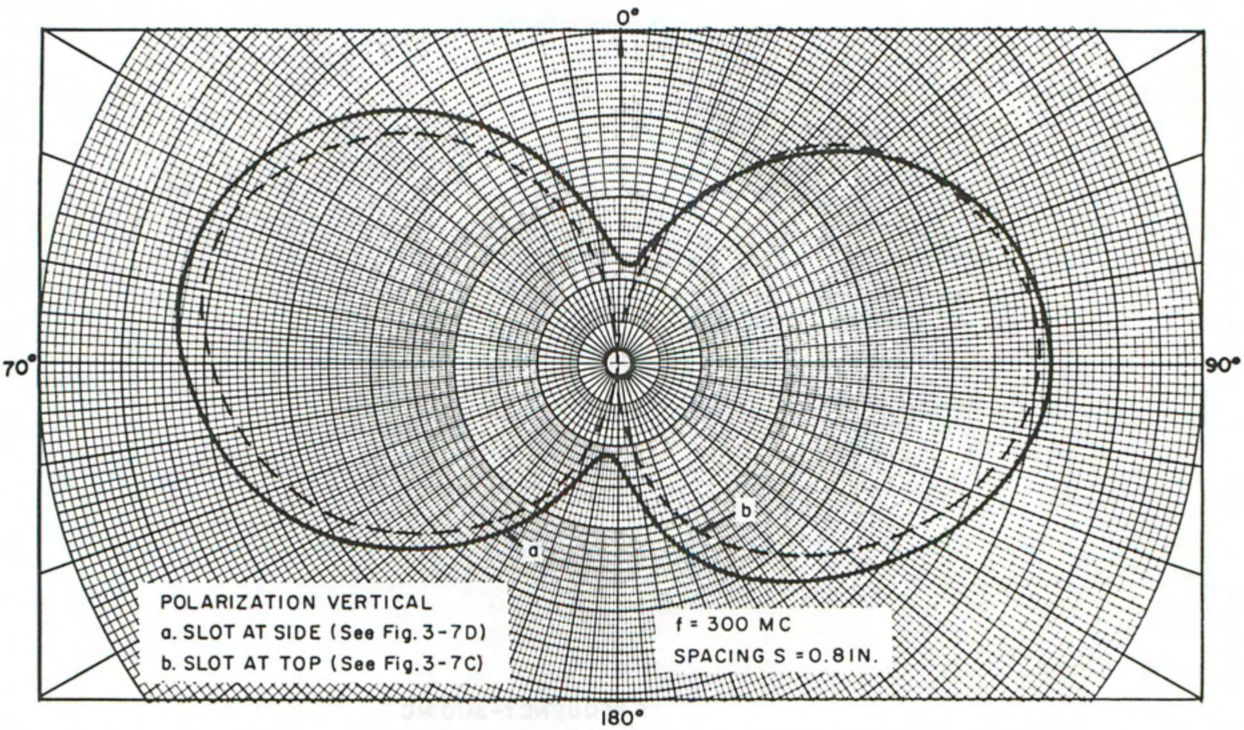

Figure 3-12 (S). Radiation Pattern for Transverse Loop Antenna (Oscillator, Figure 3-11) (U)

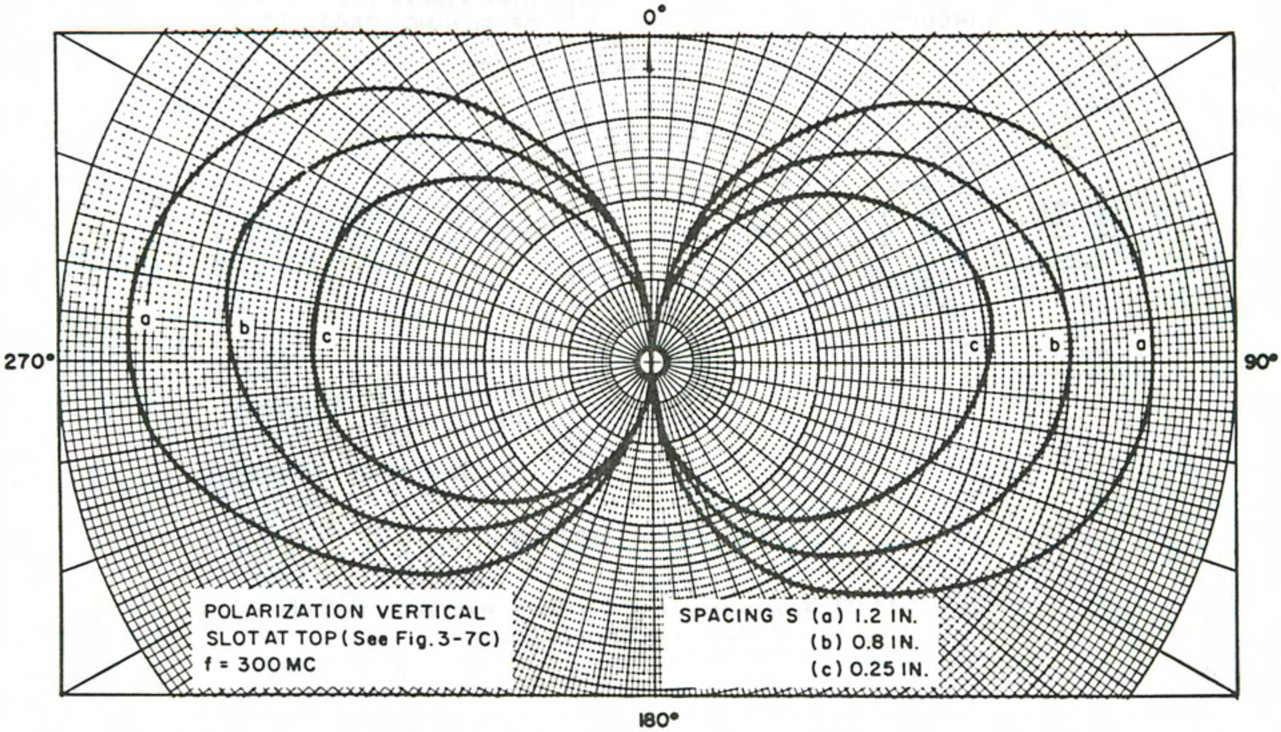

Figure 3-13 (S). Radiation Patterns for Transverse Loop Antenna (Oscillator, Figure 3-11) as Spacing Between Loop and Body is Changed (U)

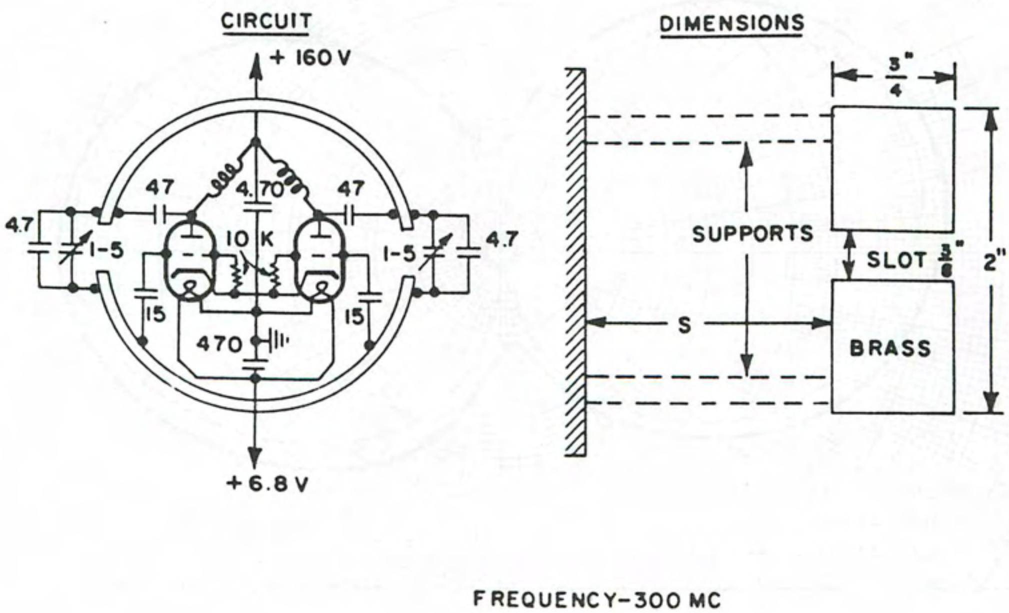

Figure 3-14 (S). Transverse Loop Push-Pull Oscillator with Narrow Cylinder Resonant Circuit (U)

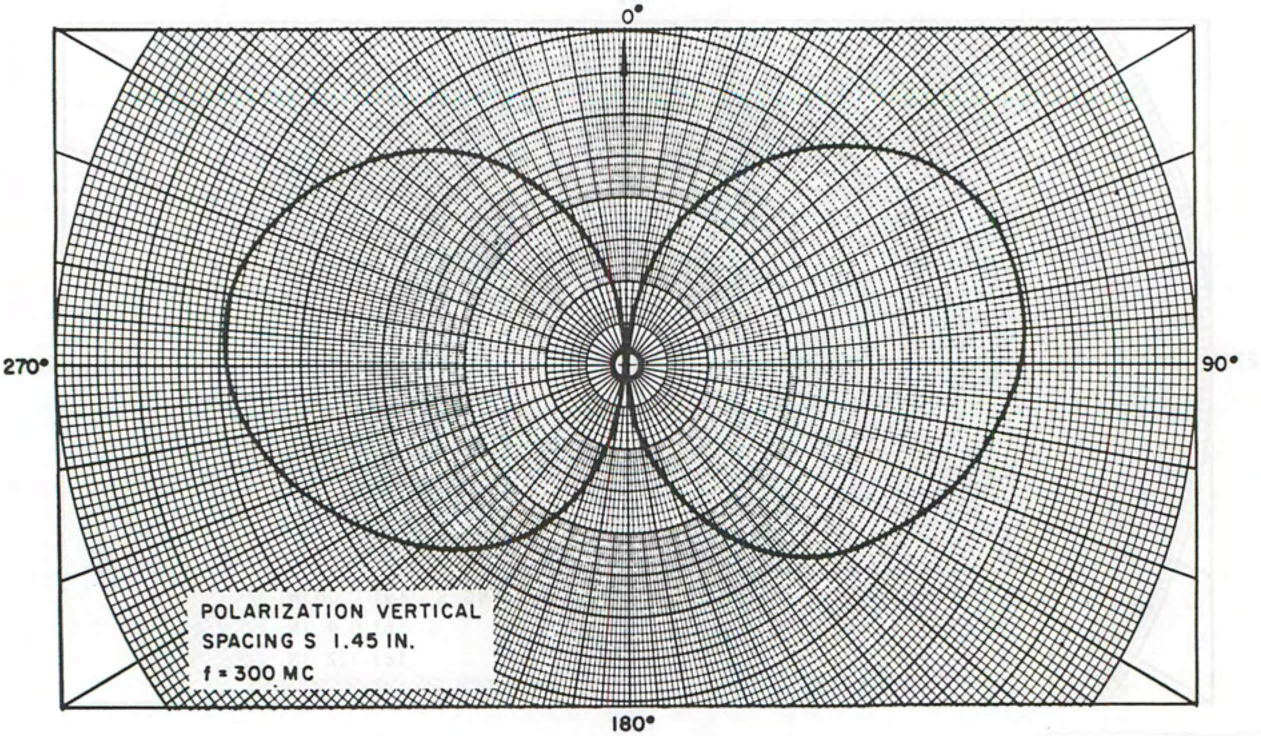

Figure 3-15 (S). Radiation Pattern for Transverse Loop Antenna (Oscillator, Figure 3-14) (U)

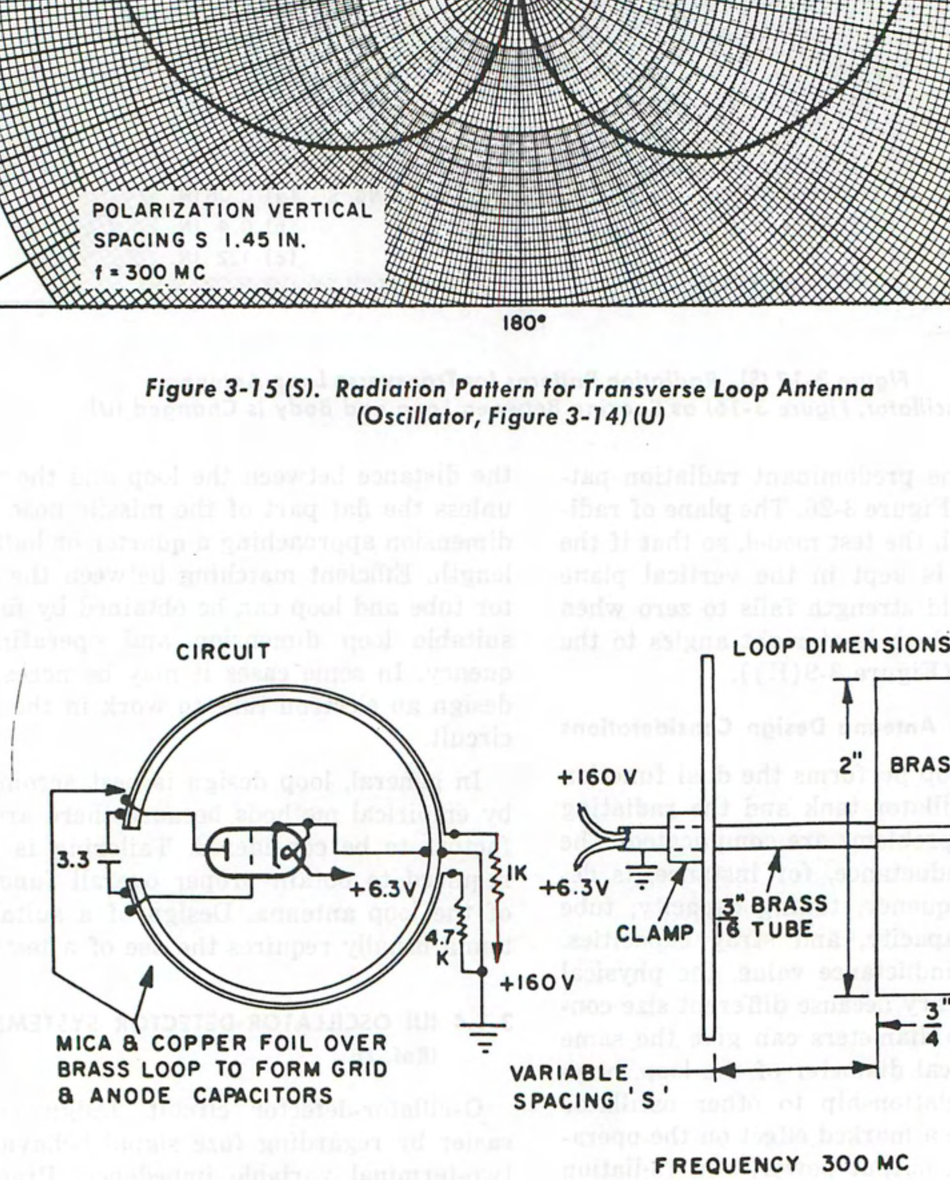

Figure 3-16 (S). Transverse Loop Oscillator with Narrow Cylinder Resonant Circuit (U)

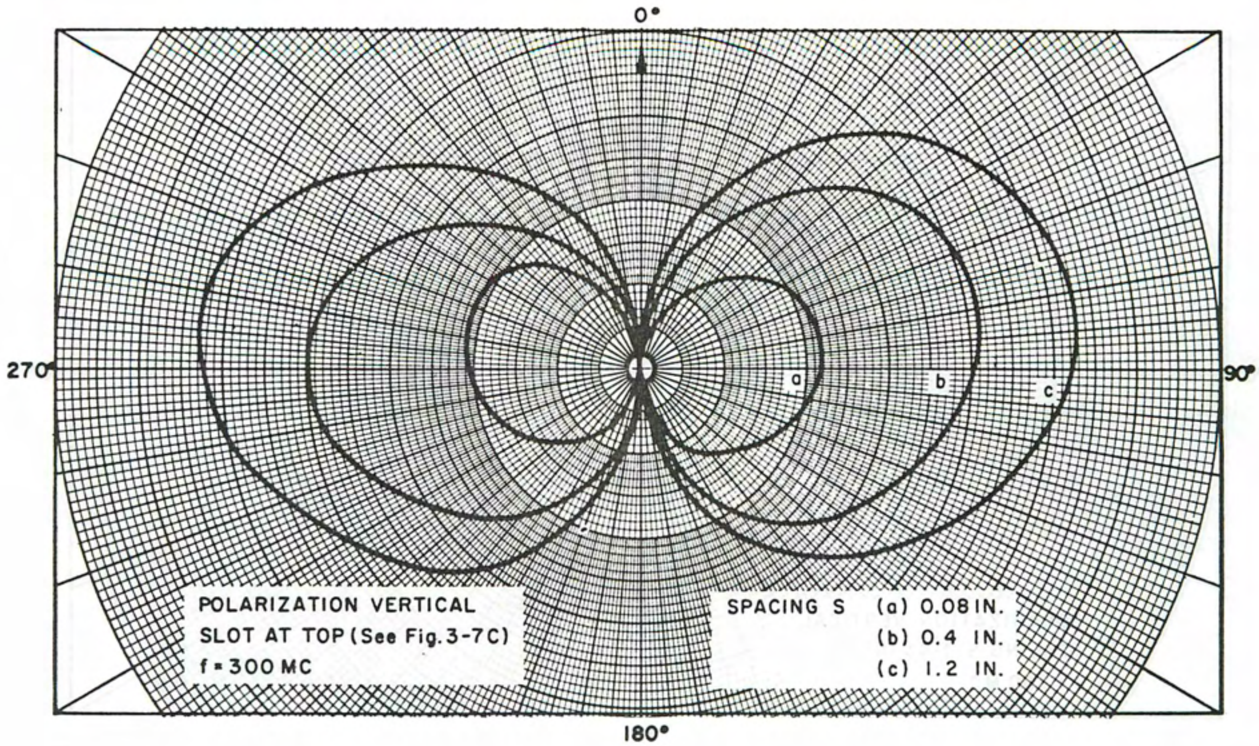

Figure 3-17 (S). Radiation Patterns for Transverse Loop Antenna (Oscillator, Figure 3-16) as Spacing Between Loop and Body is Changed (U)

through 3-28. The predominant radiation pattern is shown in Figure 3-26. The plane of radiation rotates with the test model, so that if the pickup antenna is kept in the vertical plane the measured field strength falls to zero when the plane of the loop is at right angles to the pickup antenna (Figure 3-9(H)).

3-1.3.10 (U) Loop Antenna Design Considerations

Because the loop performs the dual function of being the oscillator tank and the radiating element, design problems are complicated. The value of tank inductance, for instance, is determined by frequency, tuning capacity, tube interelectrode capacity, and stray capacities. For a required inductance value, the physical dimensions can vary because different size conductors and loop diameters can give the same value. The physical diameter of the loop, however, and its relationship to other oscillator components have a marked effect on the operation of the tube, output power, and radiation pattern.

Experiments indicate that little control of the radiation pattern can be obtained by changing the distance between the loop and the missile, unless the flat part of the missile nose is of a dimension approaching a quarter or half wavelength. Efficient matching between the oscillator tube and loop can be obtained by finding a suitable loop dimension and operating frequency. In some cases it may be necessary to design an electron tube to work in the desired circuit.

In general, loop design is best accomplished by empirical methods because there are many factors to be considered. Tailoring is usually required to obtain proper overall functioning of the loop antenna. Design of a suitable antenna usually requires the use of a test model.

3-1.4 (U) OSCILLATOR-DETECTOR SYSTEMS (Ref. 1)

Oscillator-detector circuit design is made easier by regarding fuze signal behavior as a two-terminal variable impedance. Practically, this impedance can be considered as the parallel combination of constant reactance and a variable radiation resistance. The design problem

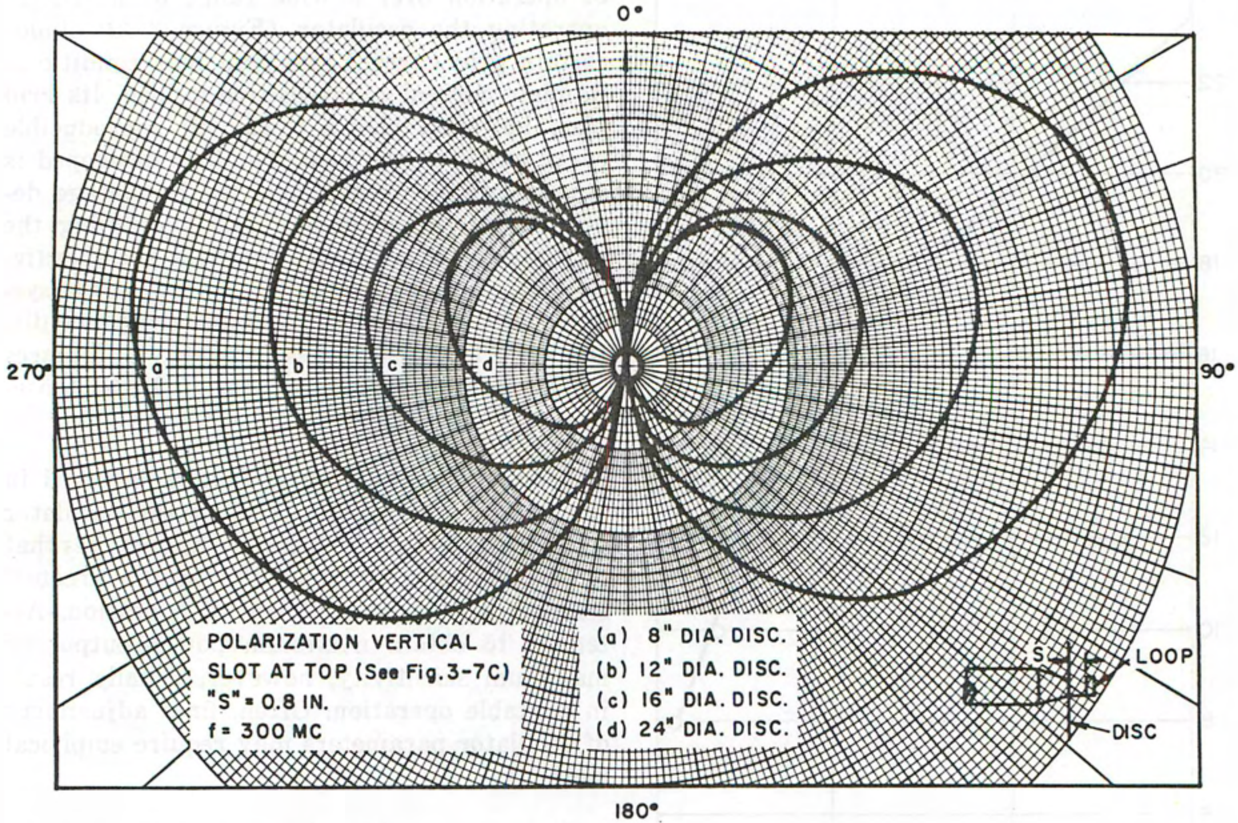

Figure 3-18 (S). Radiation Patterns for Transverse Loop Antenna (Oscillator, Figure 3-14) Showing Effect of Disc Size Behind Loop (U)

can be simplified to that of an oscillator feeding a variable resistance load.

The operating frequency as well as the fuze and missile dimensions determine the net radiation resistance. Early fuze and missile combinations had radiation loads from about 1,500 to 150,000 ohms. Larger missile-fuze combinations have lower radiation resistances; smaller projectiles, mortar projectiles for example, present a radiation resistance from about 6,000 to 100,000 ohms to the oscillator.

3-1.4.1 (U) Basic RF System

The most elementary RF system considered for a proximity fuze can be considered as an oscillating detector. Essentially, it is a heavily loaded, low-power oscillator that operates under class A grid conditions. It develops its own grid bias across a grid leak resistor of about 1 megohm, and the output voltage is developed across a plate load resistor of about 50 K ohms. The antenna must be coupled tight enough to place the oscillator on the verge of instability from overload. Under these conditions the plate current is a sensitive function of the load resistance. Such a circuit converts radiation resistance variation into an audio signal across the plate resistor. Unfortunately this circuit is considered unsuitable for fuzes because it has a small range of radiation load for satisfactory operation and requires critical load coupling adjustment.

3-1.4.2 (U) Oscillator-Diode

This type of system separates the function of RF generation and detection. A stable power oscillator is inductively coupled to the antenna circuit. A tuned diode detector is also coupled to the antenna circuit for detecting the Doppler frequency beats. The circuit can be simplified by combining the tuned diode and antenna coupling functions as shown in Figure 3-29.

The oscillator-diode system has several disadvantages, primarily that it is sensitive to

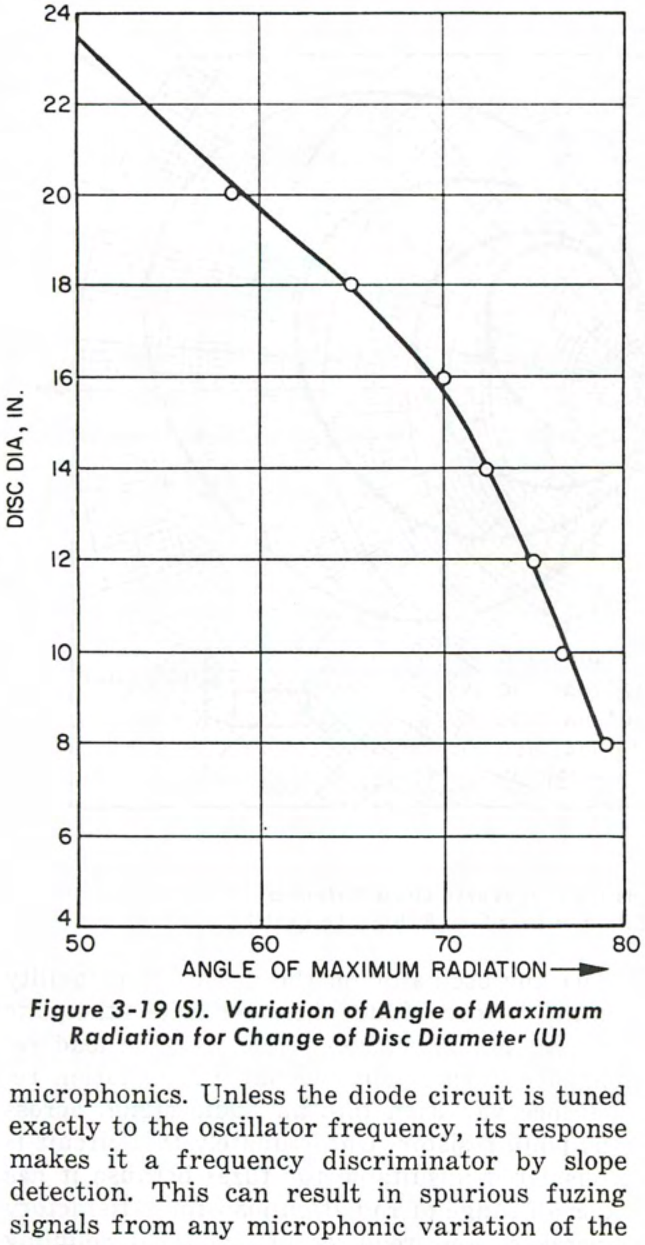

Figure 3-19 (S). Variation of Angle of Maximum Radiation for Change of Disc Diameter (U)

microphonics. Unless the diode circuit is tuned exactly to the oscillator frequency, its response makes it a frequency discriminator by slope detection. This can result in spurious fuzing signals from any microphonic variation of the oscillator tube interelectrode capacitances. Other disadvantages are that very precise tuning of the diode-antenna circuit is necessary, which results in production problems; and component aging sometimes detunes the system, with attendant fuze malfunction.

3-1.4.3 (U) Reaction Grid Detector

The reaction grid detector (RGD) is used extensively in proximity fuzes for bombs, rockets, mortars and projectiles. The grid voltage for this type of oscillator is dependent on the oscillator load, and the oscillator is capable of operation over a wide range of loads. By operating the oscillator (Figure 3-30) under certain grid current and grid bias conditions, its plate current is insensitive to load. Its grid bias, however, shows a smooth reproducible curve based on the load. The bias developed is almost exactly proportional to the voltage developed on the antenna. Tightly coupling the oscillator to the antenna broadens the selectivity of the coupling circuits and makes the system insensitive to small antenna reactance differences. This also makes frequency differences among individual oscillators of little consequence.

There are many critical factors involved in the design of an RGD. Setting the oscillator parameters so that its behavior approaches that of an ideal generator results in the greatest stability and reproducibility of operation. Attempts to obtain maximum power output or maximum sensitivity, however, usually result in unstable operation. Often, final adjustment of oscillator parameters may require empirical methods.

Generally, within the range of operating conditions, increasing the grid drive gives high grid bias and high plate current with lower internal resistance. Increasing the bias, however, tends to increase the sensitivity, whereas the decrease of internal resistance usually tends to lower the sensitivity. This effect, arising because of the high-shunt radiation resistances encountered, leads to an increase of mismatch with decreased internal resistance. This high bias decays exponentially with time at a rate determined by the RC time constant of the grid resistance value and the grid storage capacitor. When the bias goes down to a value at which oscillation will start, the cycle repeats and the tube stops oscillating. This starting and stopping is called squegging.

The instability that appears as self-modulation is of the same nature, but of a lesser degree. Here, too, the oscillation amplitude and grid bias increase with time, but before the tube stops oscillating, a temporary equilibrium between amplitude and bias is reached. Because of the time lag betwen an amplitude change and the resulting bias change, this equilibrium

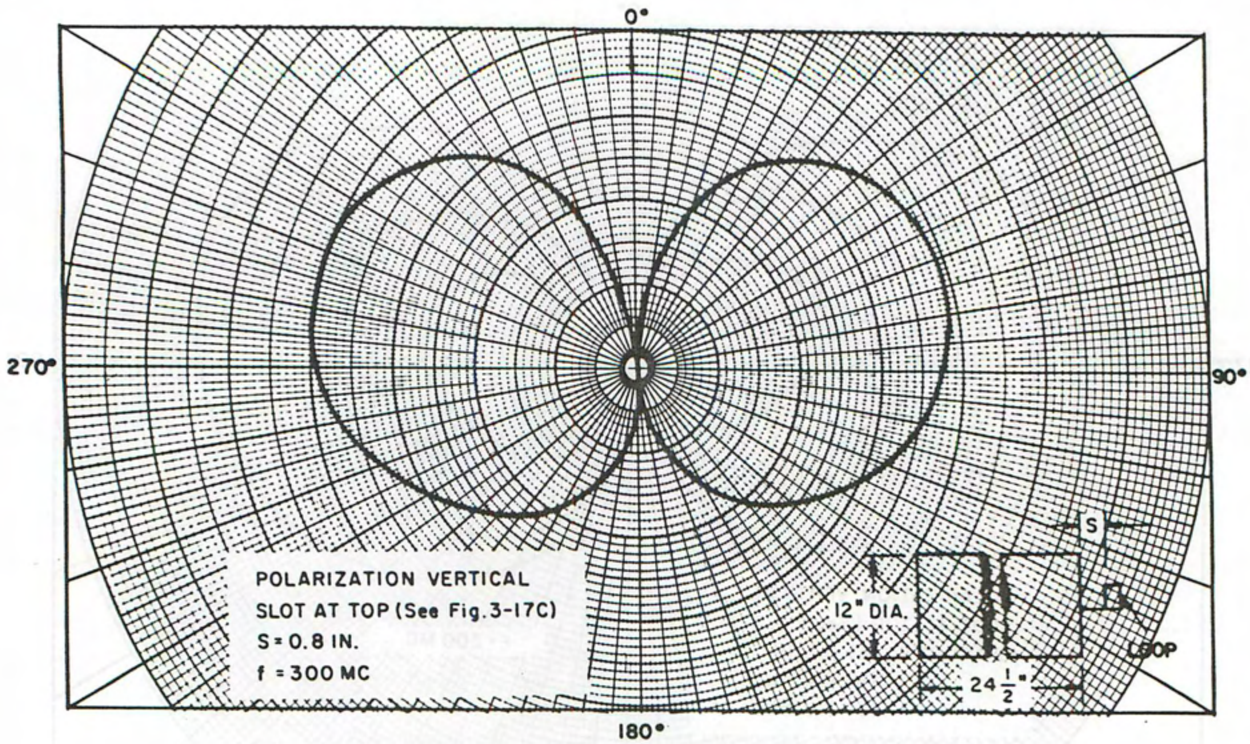

Figure 3-20 (S). Radiation Pattern for Transverse Loop Antenna (Oscillator, Figure 3-14) Mounted on Cylinder Closed at Ends (U)

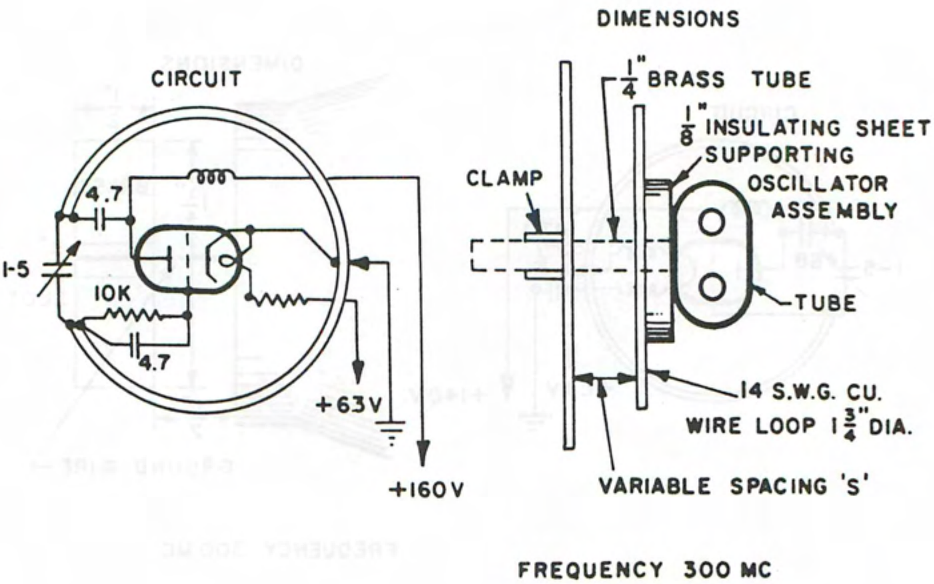

Figure 3-21 (S). Transverse Loop Oscillator with Wire Resonant Circuit (U)

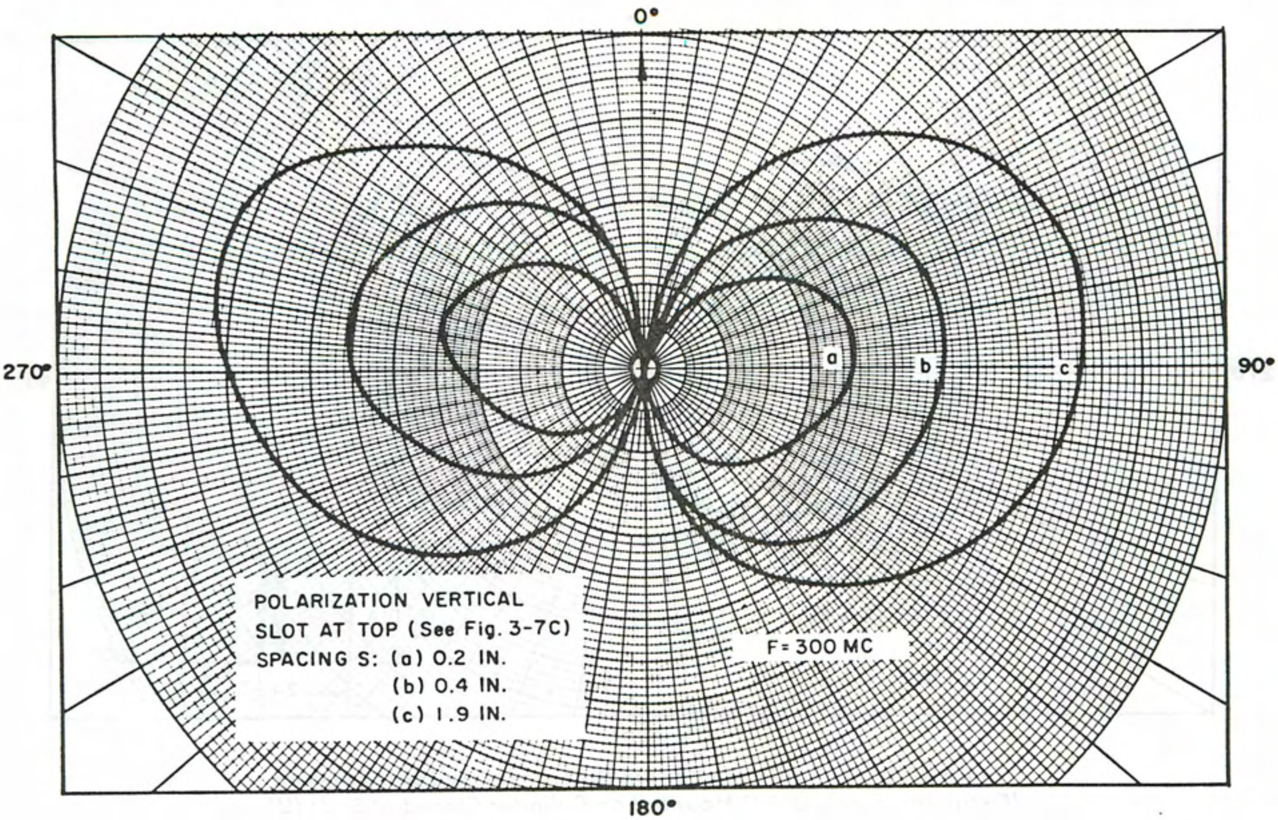

Figure 3-22 (S). Radiation Patterns for Transverse Loop Antenna (Oscillator, Figure 3-21) as Spacing Between Loop and Body Changes (U)

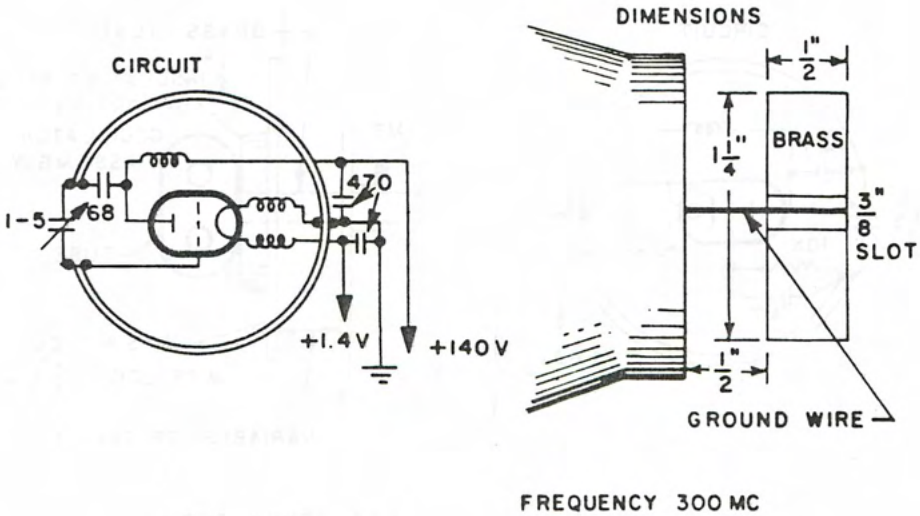

Figure 3-23 (S). Transverse Loop Oscillator with Small Diameter Cylindrical Resonant Circuit (U)

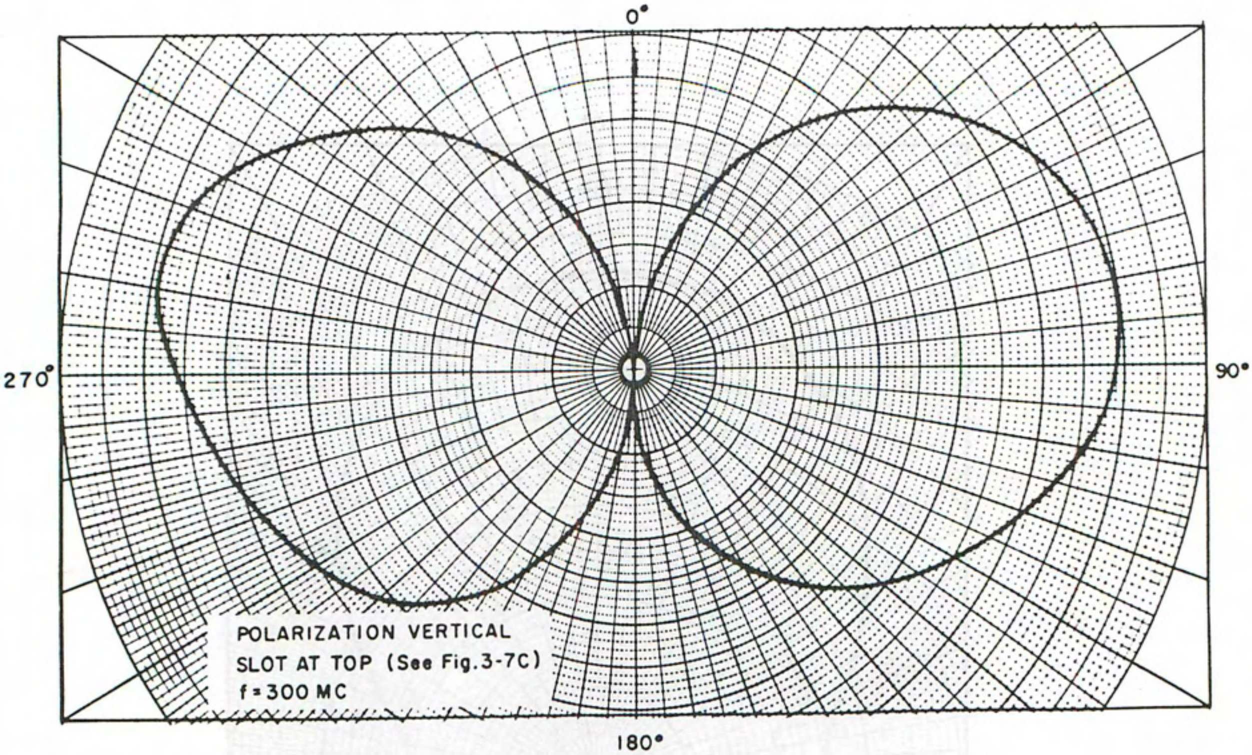

Figure 3-24 (S). Radiation Pattern for Transverse Loop Antenna (Oscillator, Figure 3-23) (U)

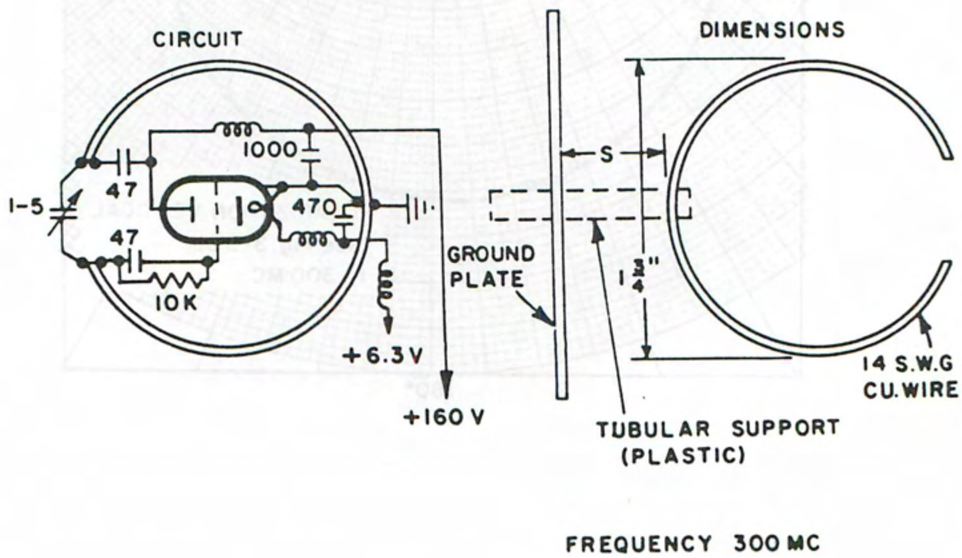

Figure 3-25 (S). Longitudinal Loop Oscillator with Wire Resonant Circuit (U)

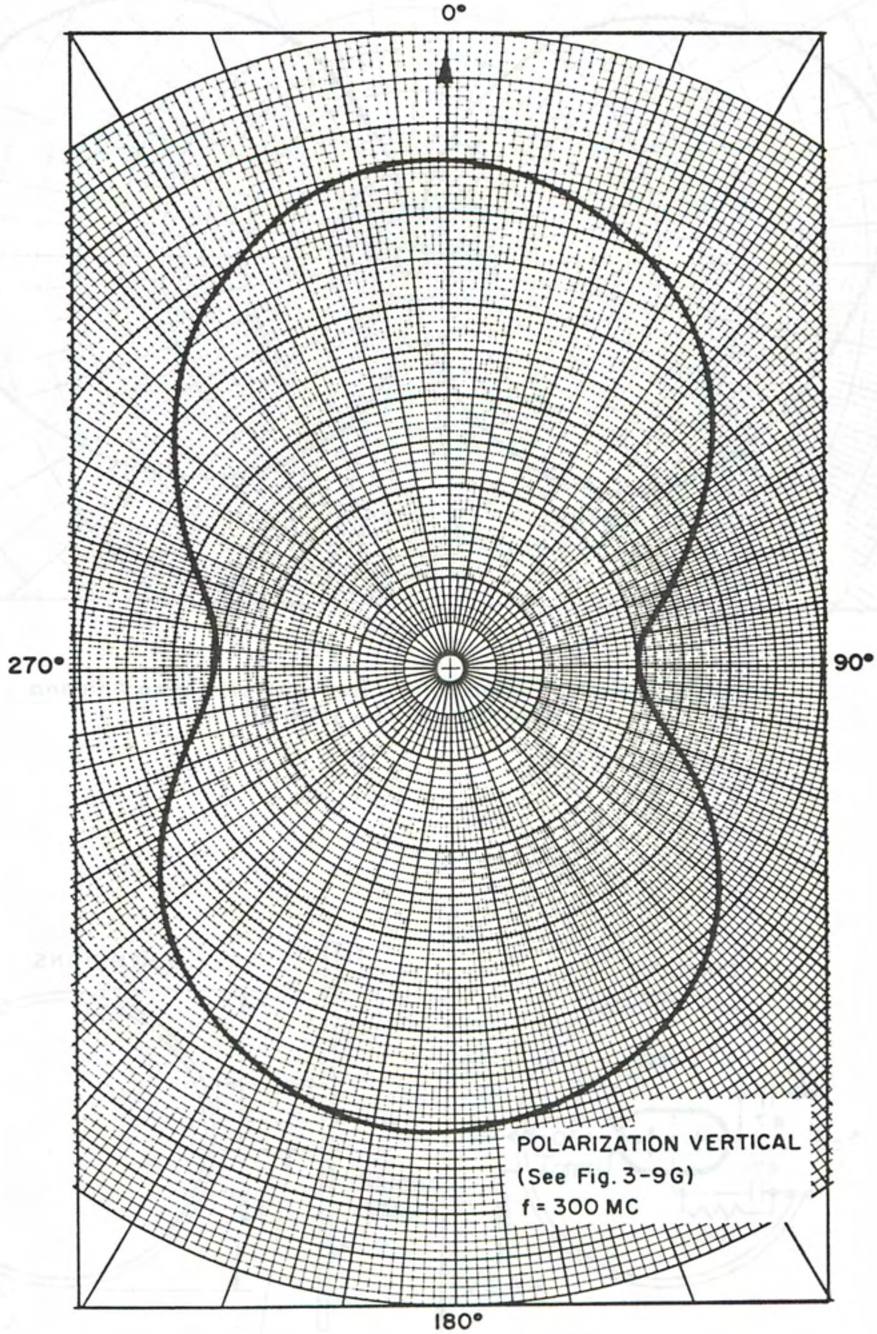

Figure 3-26 (S). Radiation Pattern for Longitudinal Loop Antenna (Oscillator, Figure 3-25) (U)

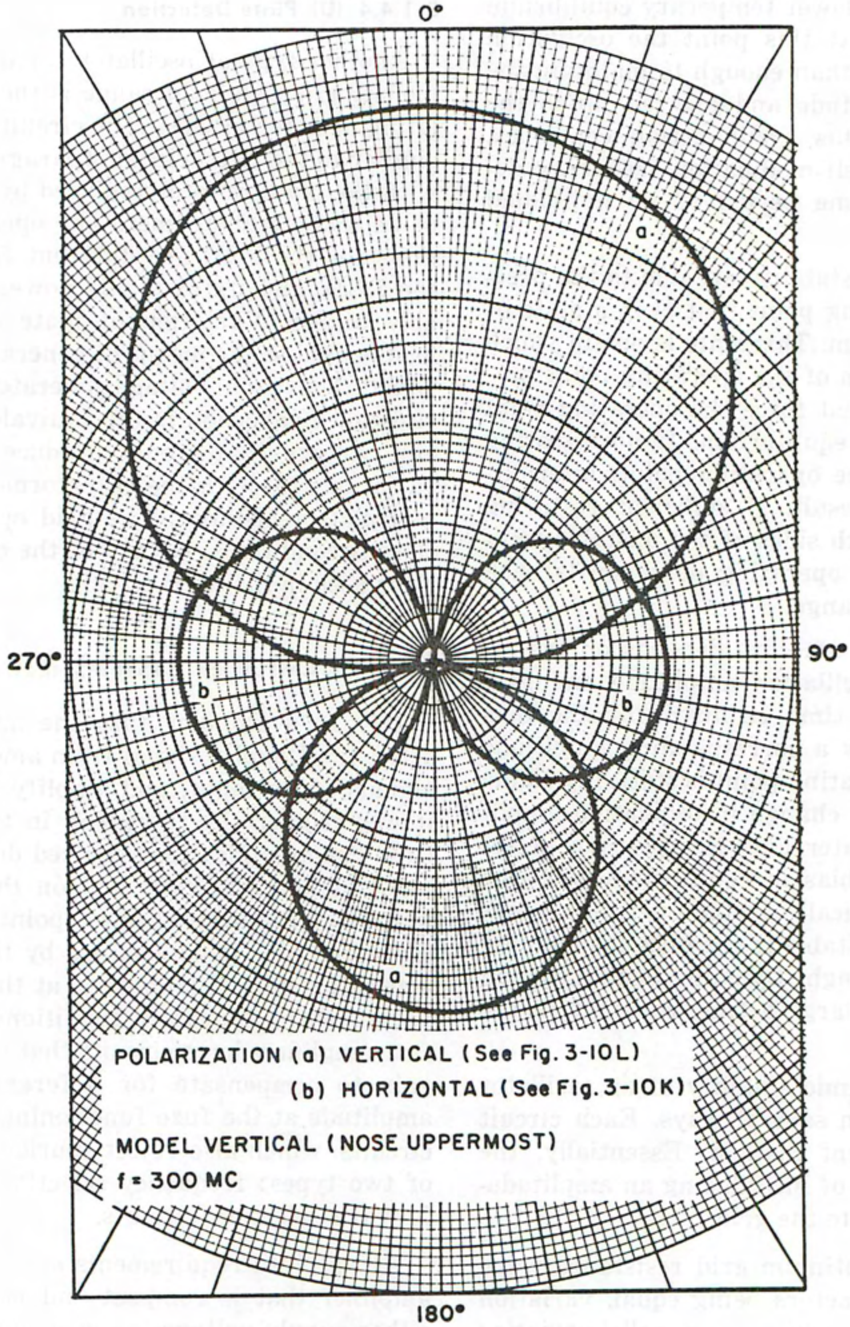

Figure 3-27 (S). Radiation Patterns for Longitudinal Loop Antenna (Oscillator, Figure 3-25); Test Model Vertical, with Nose Uppermost (U)

is not stable but is a condition where the oscillation amplitude is not sufficient to maintain the bias. Both start to decrease and continue decreasing until a lower temporary equilibrium state is reached. At this point the oscillation amplitude is more than enough to maintain the bias, so the amplitude and bias go up to the previous value. This cyclic action continues, with a resulting self-modulation frequency depending on the time period of an individual cycle.

Both types of instability are due to the presence of an operating point that is in a state of unstable equilibrium. This state is one in which any small deviation of the operating point produces conditions that force the operating point still further from equilibrium. If no restoring force is met by the operating point, intermittent oscillations result. If sufficient restoring force is met on both sides of the unstable equilibrium point, the operating point shifts back and forth over a range.

Operating point stability depends on the relation between oscillation amplitude and grid bias, and on the time required for the bias variation to follow a corresponding amplitude variation. An operating point is statically stable if a small induced change in oscillation amplitude causes a greater bias change than necessary to keep the bias in equilibrium with the amplitude. A statically stable operating point is dynamically unstable if the bias change does not occur fast enough. Dynamic instability can be caused by too large a time constant in the grid-bias circuit.

Static and dynamic stability of an oscillator can be achieved in several ways. Each circuit requires a different method. Essentially, the technique consists of introducing an amplitude-derived voltage onto the grid.

Selecting the optimum grid resistance value is simple. Other factors being equal, variation of grid resistance results in a parallel variation of grid bias and an opposite variation in plate current. Large grid resistances give higher bias with less plate current, resulting in higher internal resistance, until a plateau is reached. Increasing the grid resistance beyond a certain point gives negligible improvement and eventually leads to instability, or squegging. A detailed analysis of RGD design is given in Reference 1.

3-1.4.4 (U) Plate Detection

Another type of oscillator capable of accommodating a wide load range is the power oscillating detector (POD). The circuit is somewhat similar to the RGD circuit (paragraph 3-1.4.3), with the plate resistor replaced by the winding of an audio transformer. The operating conditions for the POD are different from those of the RGD, and its available power is considerably higher. Variation of plate current with load is used as the means of generating an audio signal. The signal voltage generated by the load resistance variation is the equivalent plate circuit voltage that would produce the current variations through the transformer impedance and plate resistance. The grid operates under class A conditions, instead of the class C conditions used in the RGD circuit.

3-1.5 (S) AMPLIFIER SYSTEMS (Ref. 6)

(U) In a Doppler fuze the amplifier must select the Doppler signal from among the other signals at its input, and amplify the signal so it will trigger the thyratron in the firing circuit. The amplification required depends on the input signal amplitude and on the signal amplitude at the desired burst point, because the thyratron bias is determined by the tube characteristics. Signal amplitude at the burst point varies with approach conditions. Therefore, fuze amplifiers have circuits that vary amplifier gain to compensate for differences in signal amplitude at the fuze functioning point. These circuits, which also reject spurious signals, are of two types: frequency selection circuits and M-wave selection circuits.

All specified requirements must be met by an amplifier that is compact and not affected by either supply voltages or component variation. The amplifier must be insensitive to wide ambient temperature and humidity conditions, both during the short time of use and for long periods of storage. Also, it must be sufficiently rugged not to generate noise voltages when subjected to severe vibration, and in some cases to withstand very high accelerations.

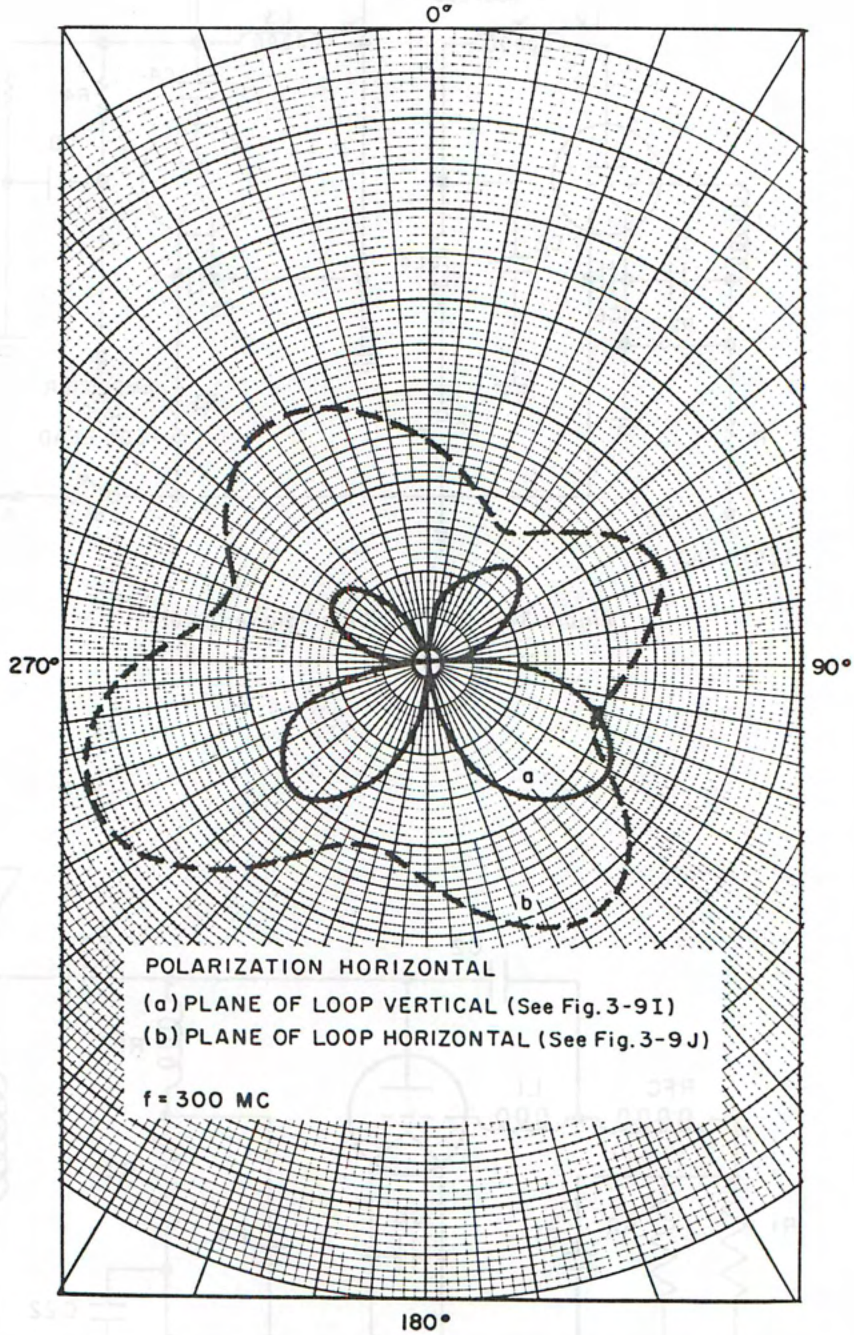

Figure 3-28 (S). Radiation Pattern for Longitudinal Loop Antenna (Oscillator, Figure 3-25), Horizontal Polarization (U)

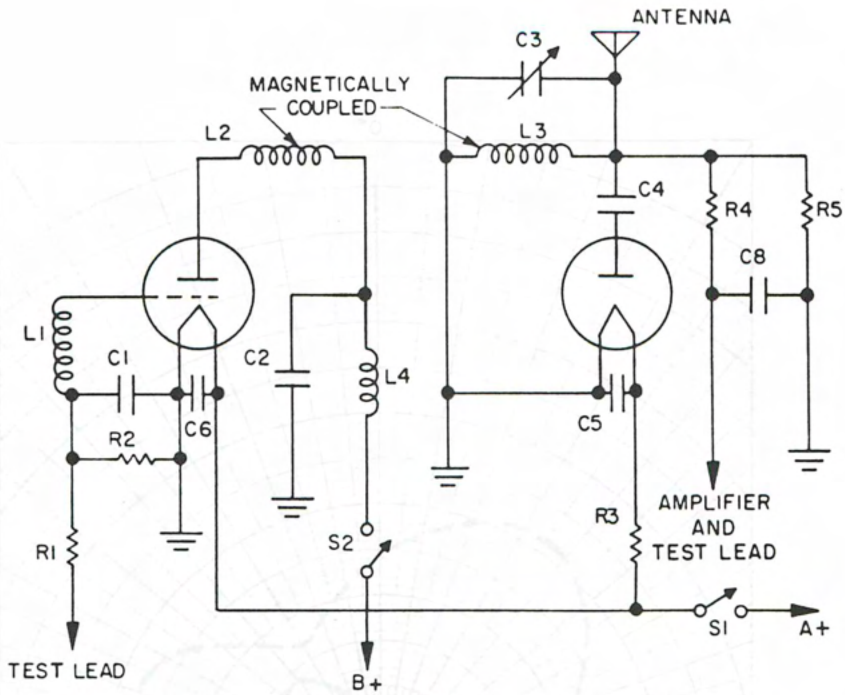

Figure 3-29 (U). Oscillator-diode Circuit

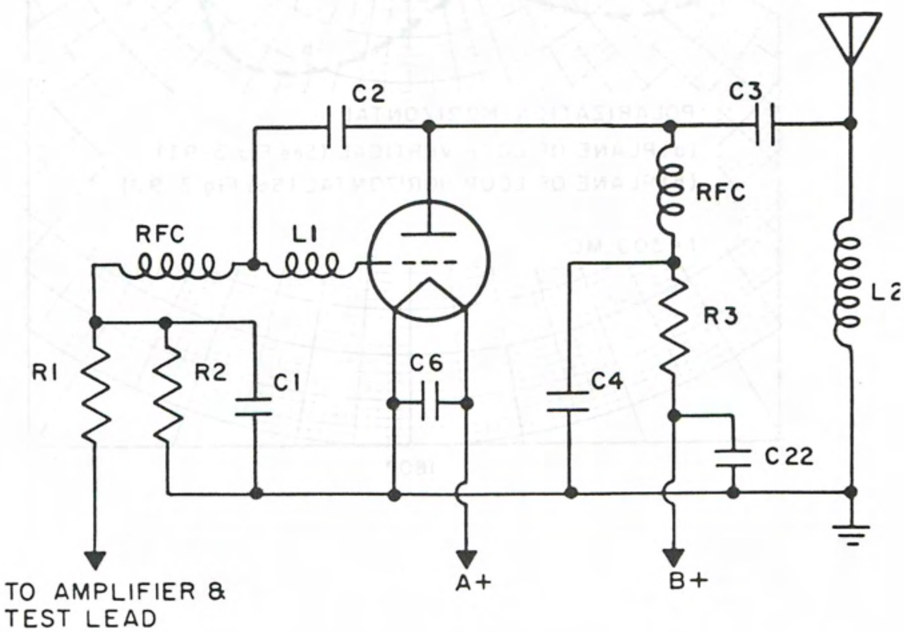

Figure 3-30 (U). Reaction Grid Detector Circuit

A more detailed discussion of amplifier requirements and characteristics can be found in Reference 1.

3-1.5.1 (U) Frequency Selection Circuits for Ground Approach Applications

In ground approach applications, both signal frequency and amplitude are partially dependent on the missile trajectory. A steep trajectory gives a greater missile-to-target velocity and the signal frequency is always higher than for a low-angle approach. The signal amplitude depends on whether a longitudinal or a transverse antenna is used. Each antenna requires different types of frequency selection circuits.

3-1.5.2 (U) Longitudinal Antenna

A longitudinal fuze antenna uses the body of the missile as the radiating element. This type of antenna makes the fuze least sensitive to targets in front of the missile (Figure 3-31), resulting in smaller signal amplitudes for a steep trajectory as compared to those obtained during a low-angle approach. The steep trajectory, however, always gives a high signal frequency. Dependence of burst height on trajectory is minimized by designing the amplifier to give approximately the same output voltage for both types of signal. This is done by peaking the amplifier response at the high end of the Doppler frequency band where the signal is weaker (Figure 3-32).

Figure 3-33 is a schematic of a typical peaked amplifier used with longitudinal antennas. Values of the RC feedback network, composed of C2, C3, C4, C5, C7, R4, and R5, are such that a phase shift of 180 degrees takes place near the upper end of the Doppler frequency band. For an input signal at this frequency, plate-to-grid feedback is regenerative, peaking the amplifier response. Above or below the peak frequency, regeneration decreases because of either decreased or increased phase shift in the feedback. Spurious signals outside the Doppler frequency band are attenuated. Adjustment of C2, connected betwen plate and grid of the amplifier tube, controls the amount of regeneration provided by the RC network. Degenerative feedback through C2 cancels part of the regenerative signal, providing a fine gain adjustment.

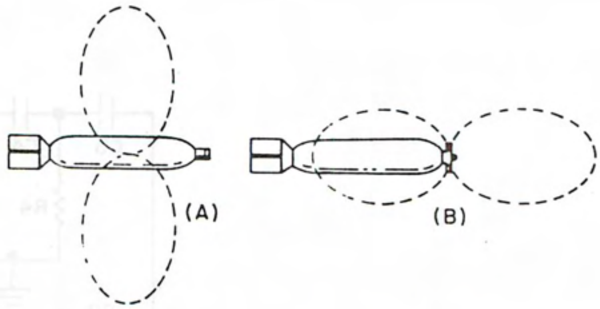

Figure 3-31 (U). Radiation Pattern of Longitudinal Fuze Antenna (A) and Transverse Fuze Antenna (B)

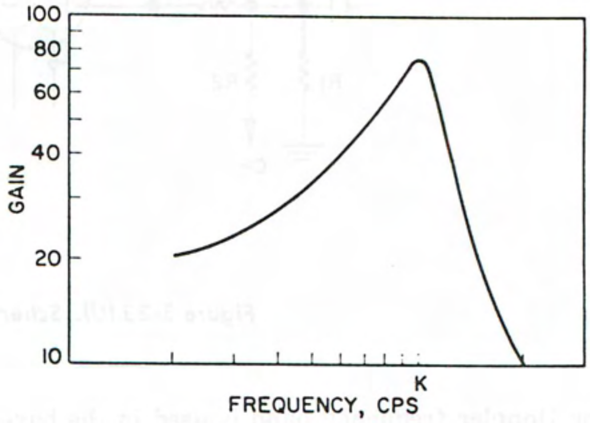

Figure 3-32 (U). Response Curve of Peaked Amplifier

3-1.5.3 (U) Transverse Antenna

A transverse antenna using a bar as a dipole is shown in Figure 3-31(B). The bar is positioned at right angles to the missile axis. Transverse antennas are most sensitive to targets ahead of the missile. Steep trajectories result in high-frequency, large amplitude signals. Low-angle approaches produce low-frequency, small amplitude signals. In surface bombing applications, where most trajectories are at 45-degree angles or less with respect to the vertical, bar-type fuzes are used. Normally, with transverse patterns, a change in trajectory that causes an appreciable difference in signal frequency results in small variations in signal amplitude. For this reason a bandpass-type amplifier with a relatively flat response over most of

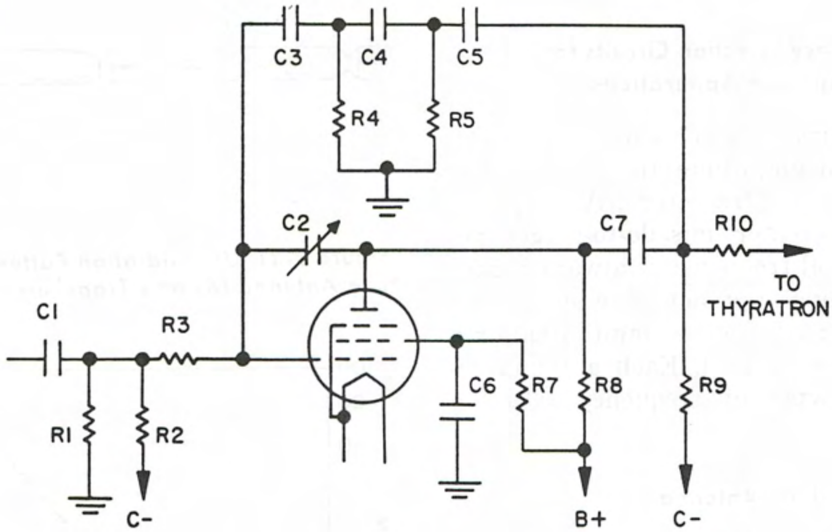

Figure 3-33 (U). Schematic of Peaked Amplifier

the Doppler frequency band is used in the bar-type fuze. This response is obtained by peaking the amplifier at both the low and high ends of the Doppler frequency band (Figure 3-34). The schematic for a typical bandpass-type amplifier for transverse antennas is given in Figure 3-35. High-frequency peaking is effected by the RC feedback network, consisting of C3, C4, C5, R6, and R7, connected between plate and grid of the tube. The series resonant LC network (L1-C1) gives low-frequency peaking in the input circuit and is resonant at low Doppler frequency.

3-1.5.4 (U) Frequency Selection Circuits for Air Target Applications

Air target applications usually require that the missile function as it passes the target. This requires a fuze with a radiation pattern similar to that in Figure 3-31(A). By comparing Figure 3-5 and Figure 3-6, it can be seen that the characteristics of the M wave developed in a fuze during a passing attack on an air target differ from those of the ground approach M wave. In the passing attack, the Doppler frequency is highest at long ranges when the missile-to-target relative velocity is greatest, and decreases rapidly as the fuze nears the target, assuming that the flight paths are not on a common axis. At the function point, the signal frequency may be equal to or less than half the head-on Doppler frequency. If the fuze functions on the basis of target signal frequency, the amplifier response curve is peaked at approximately the middle of the Doppler band.

3-1.5.5 (U) M-Wave Selection Circuits

M-wave selection circuits vary the amplifier gain in accordance with buildup characteristics of the input signal and attenuate all spurious signals. These "intelligent amplifiers," by a process of integration, are able to determine whether or not a signal has the buildup properties of the M wave. A signal will not pass through such an amplifier to the firing circuit unless it possesses certain predetermined characteristics. An M-wave selection amplifier is complicated and usually involves diode-doubling, filtering, clamping, integrating, and differentiating circuits. Such amplifiers, often

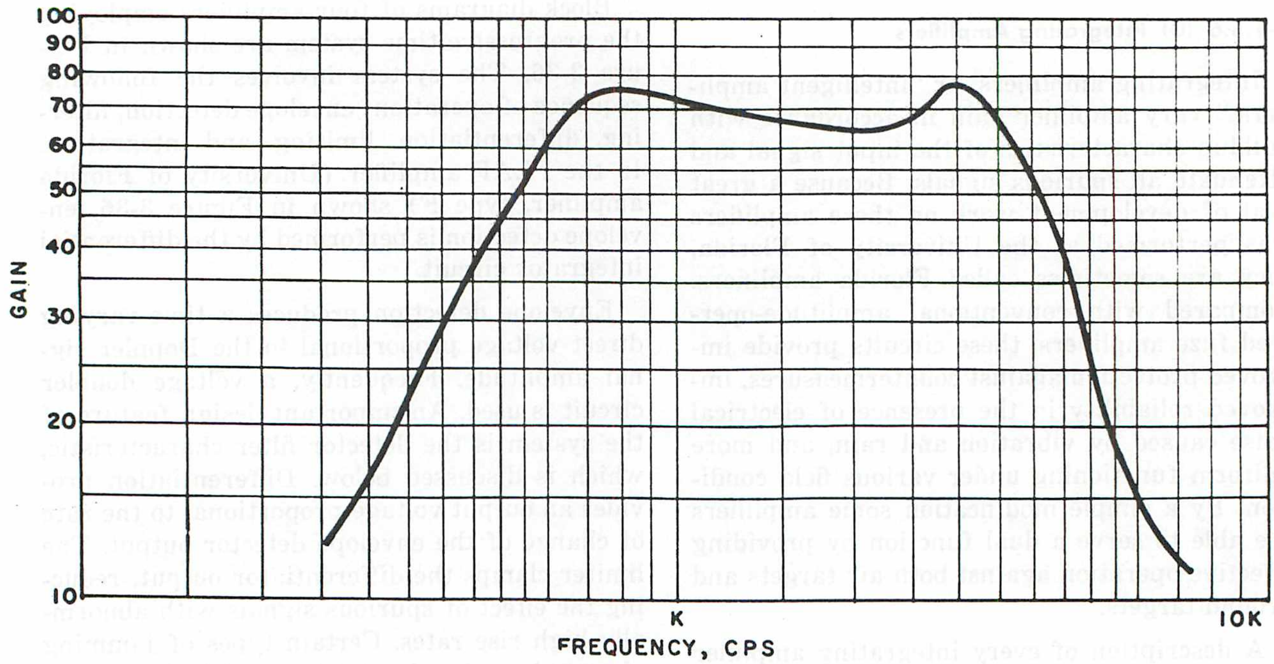

Figure 3-34 (U). Response Curve of Bandpass-type Amplifier

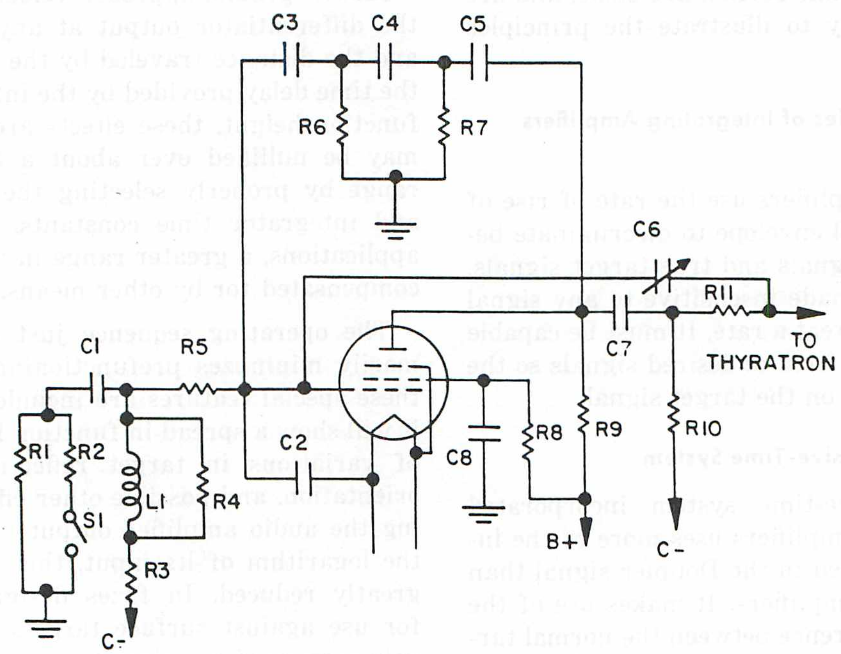

Figure 3-35 (U). Schematic of Bandpass-type Amplifier

called integrating amplifiers, intelligent amplifiers, are described in the following paragraphs.

3-1.5.6 (U) Integrating Amplifiers

Integrating amplifiers, or "intelligent amplifiers," vary amplifier gain in accordance with buildup characteristics of the input signal and attenuate all spurious signals. Because a great deal of development work on these amplifiers was performed at the University of Florida, they are sometimes called Florida amplifiers. Compared with conventional amplitude-operated fuze amplifiers, these circuits provide improved protection against countermeasures, improved reliability in the presence of electrical noise caused by vibration and rain, and more uniform functioning under various field conditions. By a simple modification some amplifiers are able to serve a dual function by providing effective operation against both air targets and ground targets.

A description of every integrating amplifier circuit is beyond the scope of this handbook. Many circuits and variations are described in References 7 through 13. These references should be consulted for application, component values, operation, and test results. The amplifiers discussed in this section are basic, and are included primarily to illustrate the principles of operation.

3-1.5.7 (U) Principles of Integrating Amplifiers (Ref. 14)

Integrating amplifiers use the rate of rise of the Doppler signal envelope to discriminate between spurious signals and true target signals. The amplifier is made insensitive to any signal that rises at too great a rate. It must be capable of rapid recovery from undesired signals so the fuze will function on the target signal.

3-1.5.8 (S) Progressive-Time System

The progressive-time system incorporated into integrating amplifiers uses more of the information contained in the Doppler signal than do conventional amplifiers. It makes use of the fundamental difference between the normal target signal and most of the conventional countermeasures signals or spurious signals that may be encountered. The normal target signal has a characteristic and well-defined amplitude buildup.

Block diagrams of four amplifiers employing the progressive-time system are shown in Figure 3-36. The system involves the following sequence of operation: envelope detection, filtering, differentiation, limiting, and integration. In the FLAF amplifier (University of Florida amplifier, type F) shown in Figure 3-36, envelope detection is performed by the differential integrator circuit.

Envelope detection produces a time-varying direct voltage proportional to the Doppler signal amplitude. Frequently, a voltage doubler circuit is used. An important design feature of the system is the detector filter characteristic, which is discussed below. Differentiation provides an output voltage proportional to the rate of change of the envelope detector output. The limiter clamps the differentiator output, reducing the effect of spurious signals with abnormally high rise rates. Certain types of jamming also produce signals of this type. The integrator serves as a time delay circuit. Its function is to prevent the thyratron from firing until the differentiator output remains above a minimum level for a predetermined length of time.

Missile ground-approach velocity affects both the differentiator output at any given height and the distance traveled by the missile during the time delay provided by the integrator. As to function height, these effects are opposite and may be nullified over about a 3-to-1 velocity range by properly selecting the differentiator and integrator time constants. In some fuze applications, a greater range in velocity can be compensated for by other means.

The operating sequence just described primarily minimizes prefunctioning. But if only these special features are included in the fuze, it will show a spread in function height because of variations in target reflectivity, antenna orientation, and possible other effects. By making the audio amplifier output proportional to the logarithm of its input, this spread can be greatly reduced. In fuzes designed primarily for use against surface targets, a fast-acting gain-compression circuit in the amplifier achieves this result.

Figure 3-37 shows idealized waveforms to

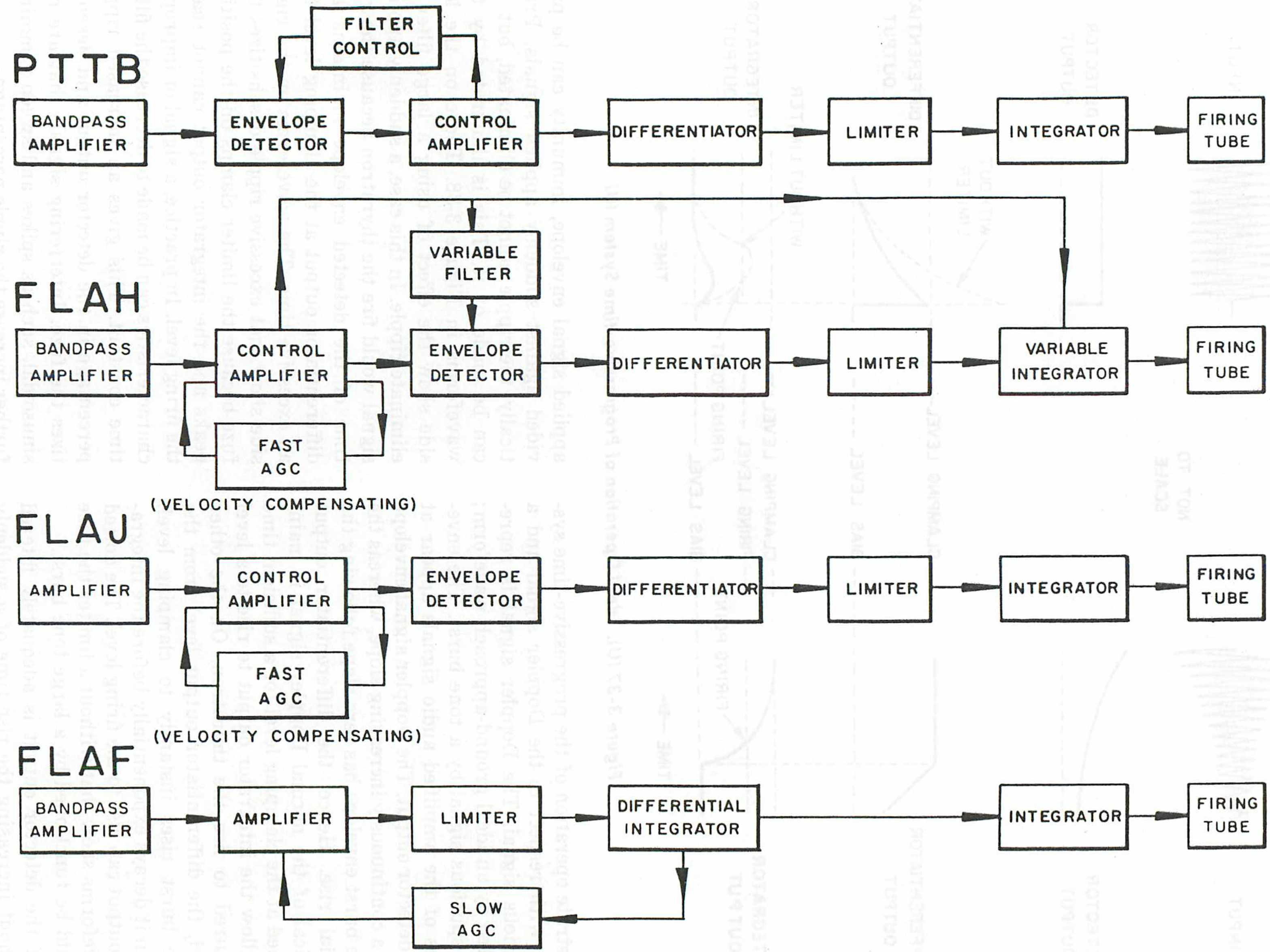

Figure 3-36 (S). Block Diagrams of PTTB, FLAH, FLAJ, and FLAF Integrating Amplifiers (U)

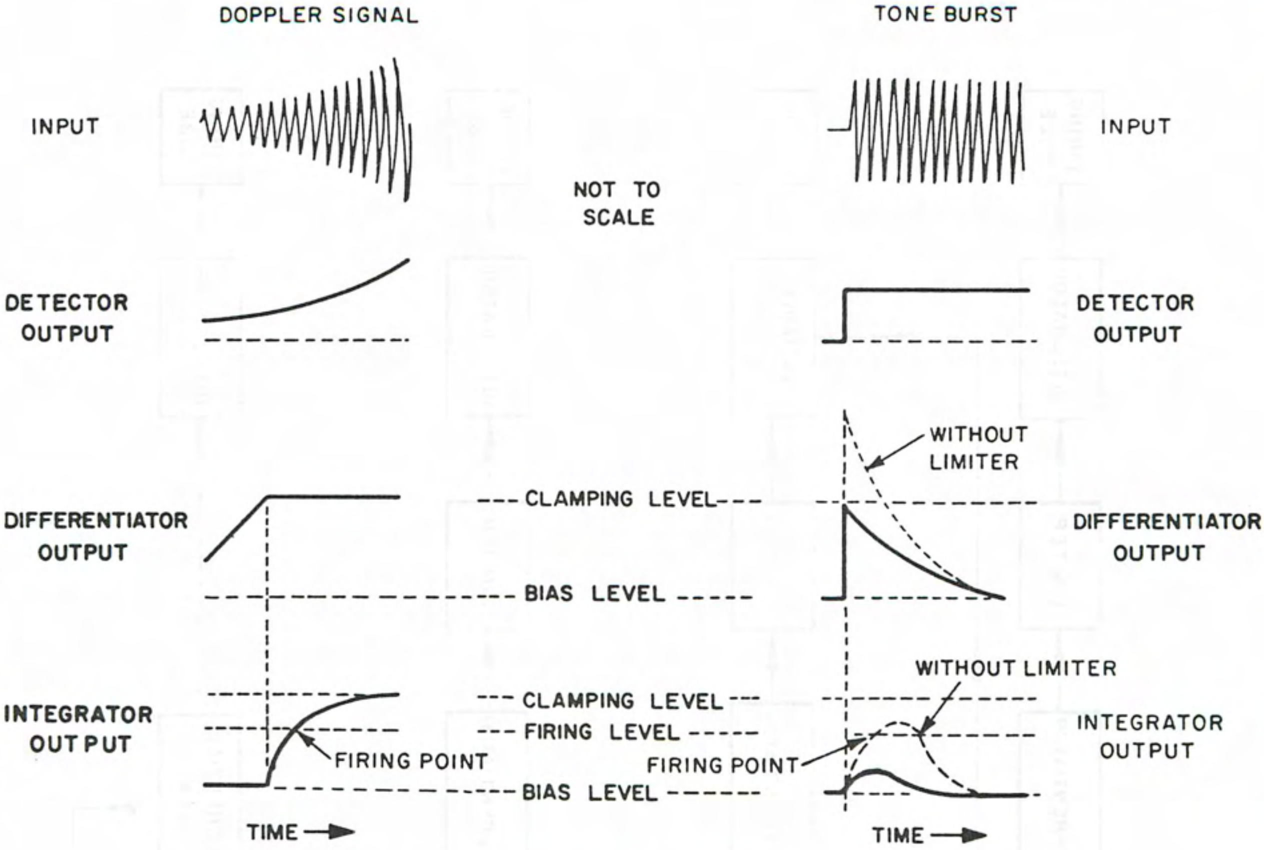

Figure 3-37 (U). Ideal Operation of Progressive-time System (U)

illustrate operation of the progressive-time system with respect to the Doppler signal and a spurious signal. The Doppler signal is represented by an ideal ground-approach waveform; the spurious signal by a tone burst. The envelopes of the amplified audio signals appear at the detector output. The Doppler signal envelope has a continuously increasing slope, whereas the tone burst envelope has zero slope following the initial rise. Hence, the differentiator output typical of the normal Doppler signal is maintained at the clamping level for a sufficient time to allow the integrator output to rise to a level required to fire the thyratron. On the other hand, the differentiator output level from the tone burst rises instantly to clamping level. Then it decays exponentially before the integrator output can rise to the firing level. The dotted waveforms show that without a limiter the fuze would be functioned by a large tone burst.

If the detector output is adequately filtered without increasing the rise time of a suddenly applied signal envelope, immunity can be provided against suddenly applied signals. Practically, the ripple cannot be eliminated, but use can be made of it. This is illustrated by the waveforms in Figure 3-38. Those on the left side show the effect of using a large filter to eliminate ripple. In this case, a suddenly applied signal would fire the thyratron because the rise time of the detected envelope maintains the differentiator output at the clamping level for an excessive time. The waveforms on the right side show that excessive ripple desensitizes the fuze because the limiter clamps on the positive peaks and the integrator output cannot reach the firing level. In practice, a signal of improper characteristics can be made to decrease the filter time constant. This gives an increased ripple percentage in the detector output and desensitizes the fuze. Interfering signals that are not sinusoidal, such as spikes and sweep jamming, further increase the ripple percentage.

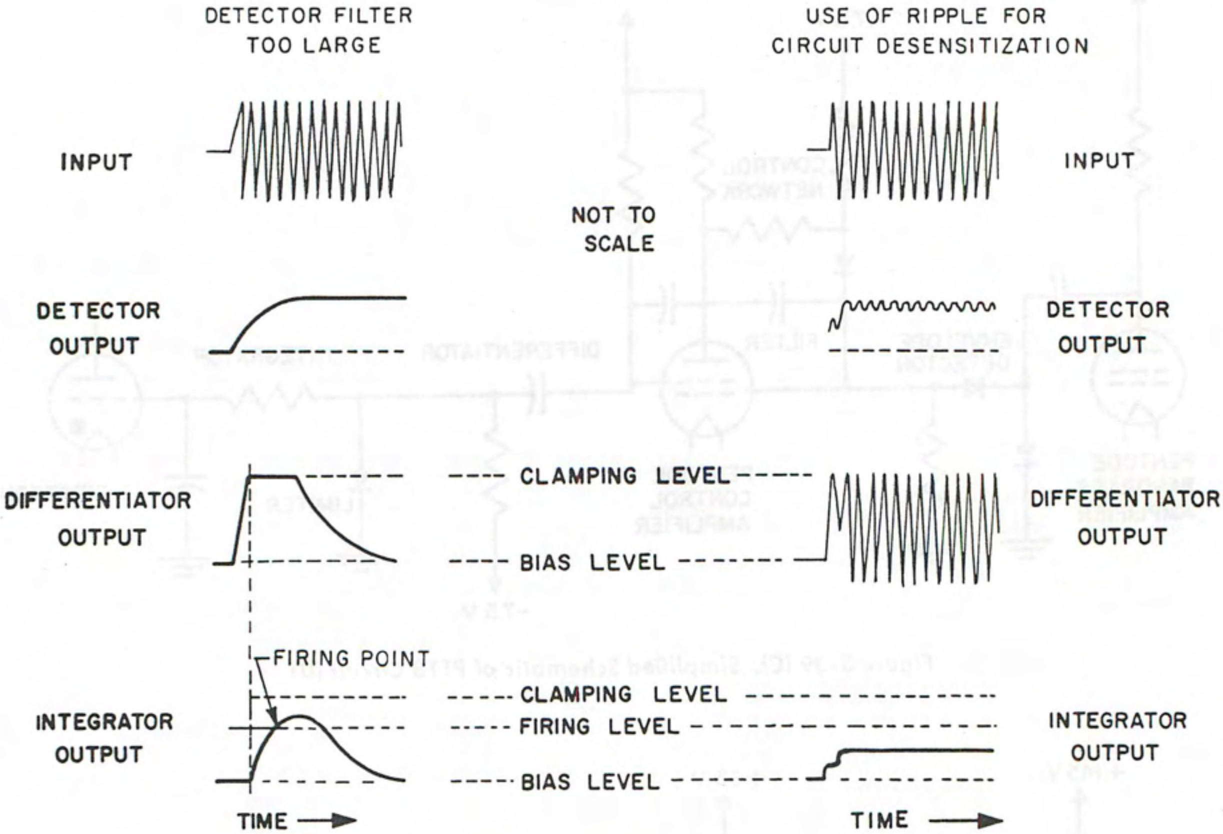

Figure 3-38 (U). Effects of Large Detector Filter, and use of Ripple for Circuit Desensitization

3-1.5.9 (S) PTTB Amplifier (Progression Time, Transverse Bomb)

The PTTB amplifier (Figure 3-39), one of the earliest applications of the progressive-time system, was designed for the T766 bomb fuze. The primary objective was to provide a high degree of immunity to interfering signals. This was achieved with the basic elements of the progression-time system, implemented by a control amplifier and a filter control network. The pentode control tube performs a dual function; from control grid to screen grid it provides d-c amplification for the output of the envelope detector, and the plate senses the application of an interfering signal. The network between the plate and grid modifies the filtering efficiency to increase the ripple percentage in the presence of spurious signals. A tone burst of any amplitude or frequency cannot prefunction this circuit, nor can a signal voltage step of either polarity.

3-1.5.10 (S) FLAH Amplifier

The FLAH circuit (Figure 3-40) is another example of the progression-time principle applied to the bomb fuze (T750). Compared to the PTTB, the FLAH circuit provides a more uniform function height as well as high resistance to prefunctioning. The control amplifier in this circuit is followed by the envelope detector, differentiator, limiter, and integrator. The envelope detector consists of an electron-coupled voltage doubler that uses grid detection and a selenium diode in the screen circuit. Both the detector filter capacitor and the integrator are connected to the control amplifier plate. This permits the efficiency of the detector filter to be reduced, and the integrator time delay to increase when an interfering signal is received. If the interfering signal persists, the compression circuit normally reduces its effect so that target signals may be received. Function-height spread (Figure 3-41) is reduced by this fast

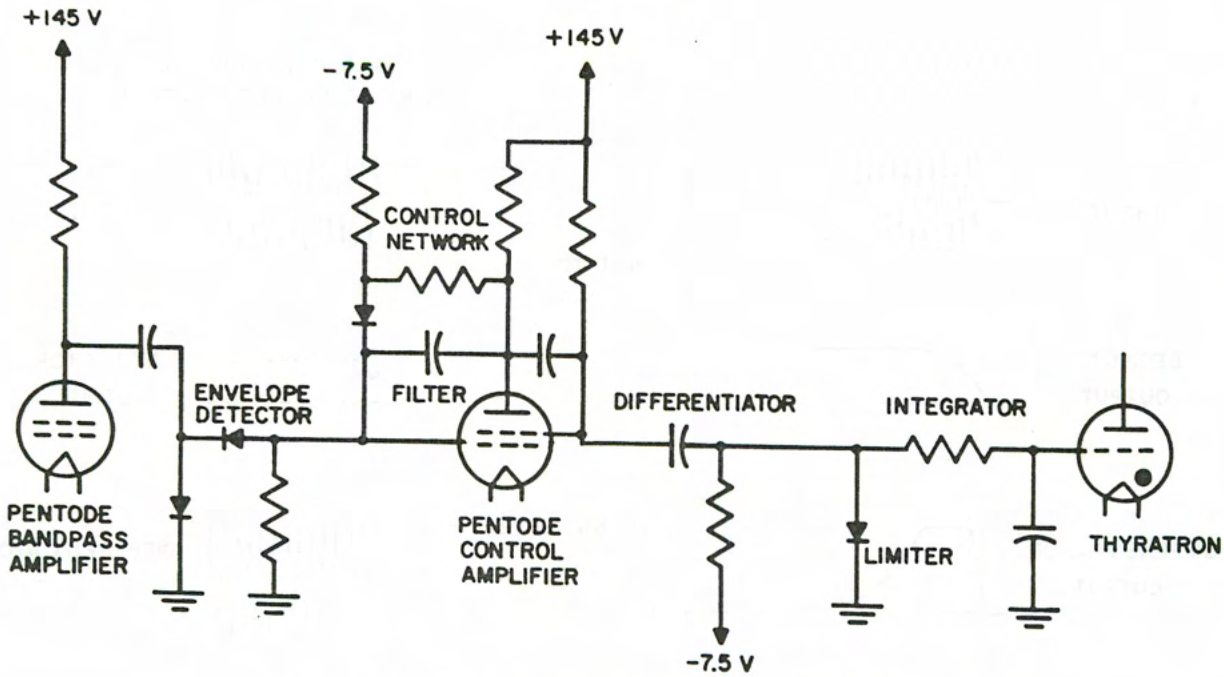

Figure 3-39 (C). Simplified Schematic of PTTB Circuit (U)

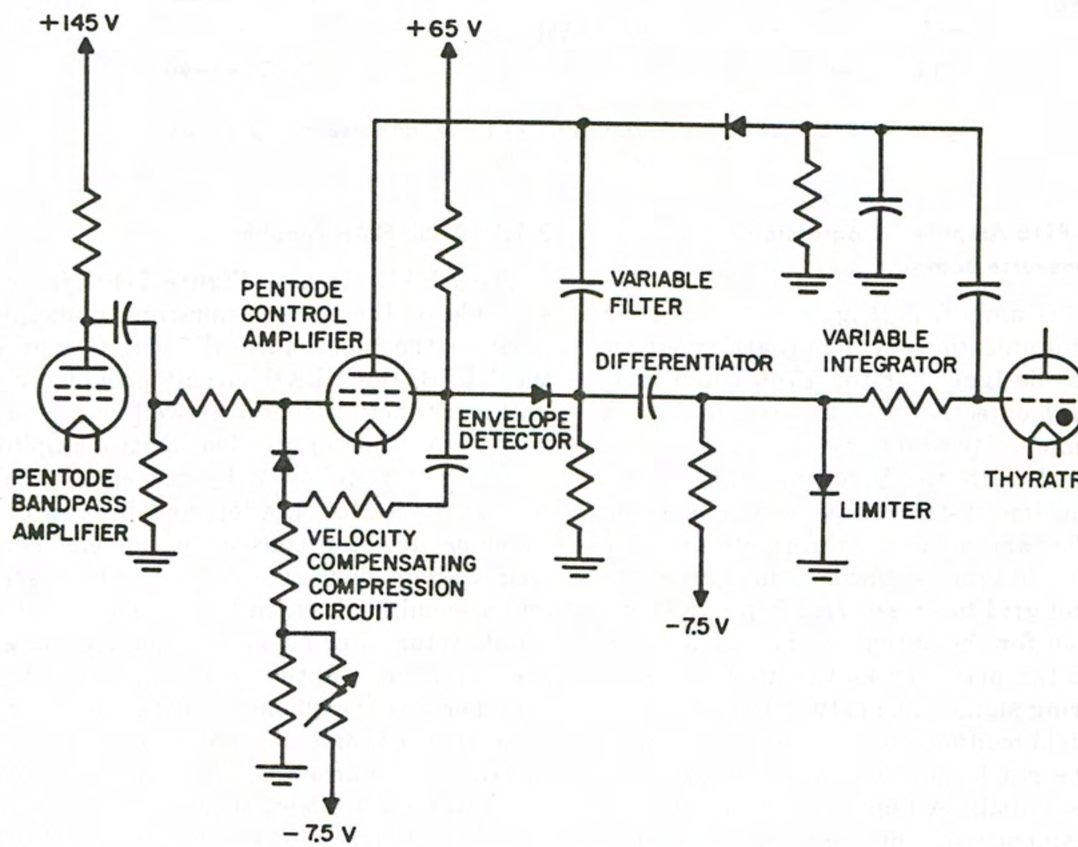

Figure 3-40 (S). Simplified Schematic of FLAH Circuit (U)

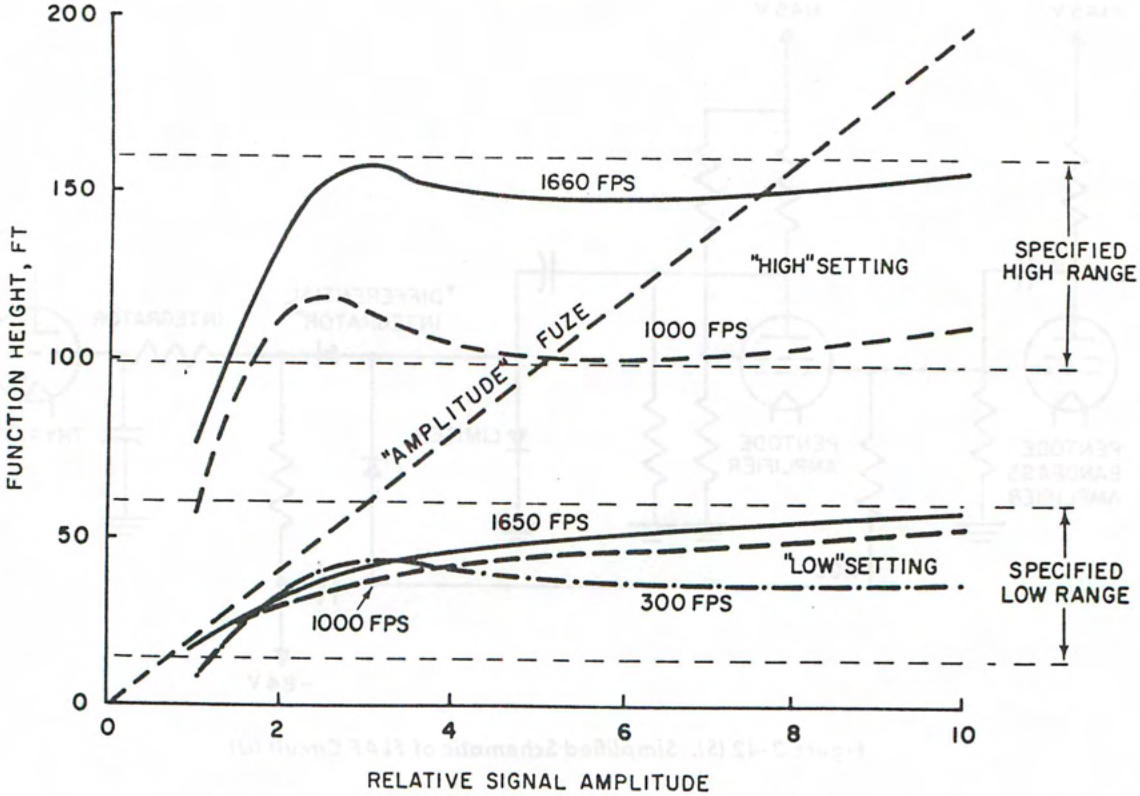

Figure 3-41 (S). Function Height Vs Relative Signal Amplitude for Various Bomb Velocities and Settings; T750 Fuze (U)

acting compression circuit. The circuit also compensates for a wide range in velocity, because it is frequency sensitive. The T750 fuze has a switch to change the amount of gain compression. This adjusts for performance within the height ranges shown by the curves.

3-1.5.11 (S) FLAF Circuit

The FLAF circuit (Figure 3-42) is used with T2061 rocket fuze. This fuze is designed primarily for air-to-air operation, and collaterally for air-to-ground operation. A novel differential-integrator combines the functions of envelope detection, differentiation, and time-delayed automatic gain control. The differential-integrator has two outputs: a differentiated or slope-sensitive output that, being limited and integrated, triggers the firing circuits; and an integrated or amplitude-sensitive output that controls the gain compression circuit. These outputs are made to interact so that fuze sensitivity is maximum when an air target is approached and minimum for the low-angle ground approach condition. This provides effective operation against both types of targets.

Operation of the FLAF in the presence of a wide variety of air target signals makes it necessarily responsive to a tone burst of the proper amplitude, frequency, and duration. Nevertheless, it cannot be triggered by a step voltage or by a continuous steady-state signal.

3-1.5.12 (S) FLAJ Circuit (Ref. 15)

The FLAJ circuit (Figure 3-43) is considered for use against ground targets only. Basically, the circuit has fast cycle-by-cycle compression obtained by a biased diode and feedback from the second-stage plate. It is compensated to have a relatively small amount of spread in function height with change in reflection coefficient. This relatively flat function height is obtained by the combined use of compression at the input of the second stage and differentiation followed by integration of the d-c envelope out of the doubler following the second stage of amplification. The circuit is further compensated

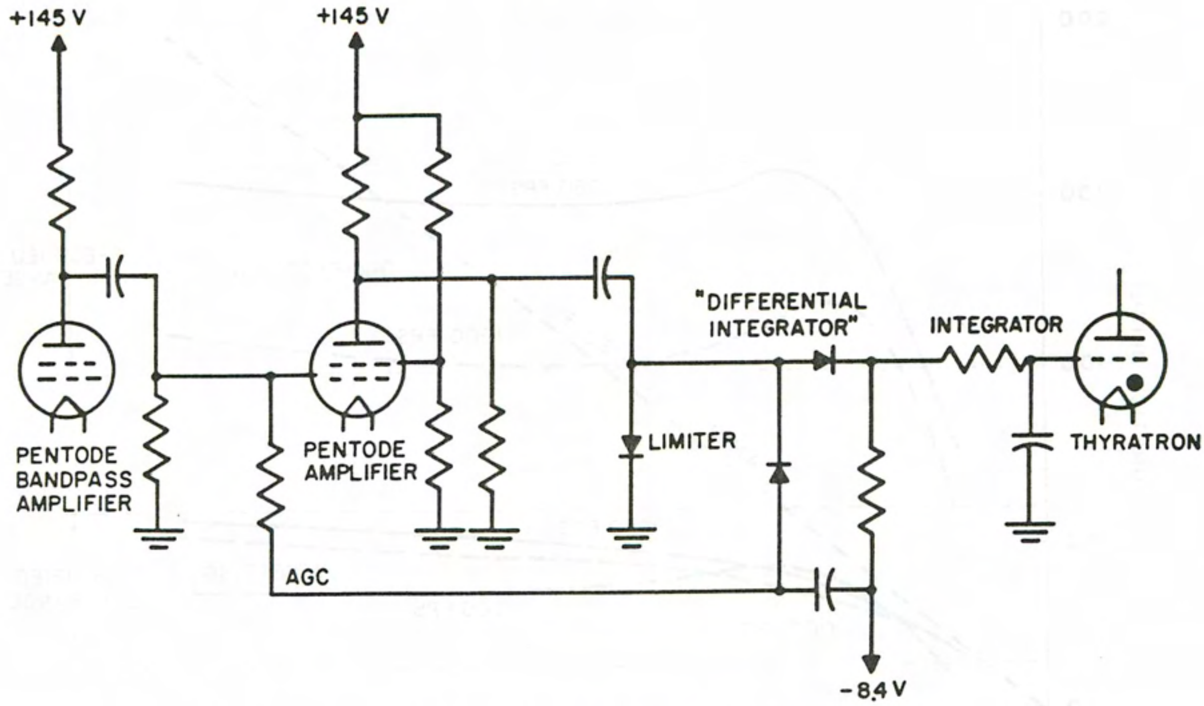

Figure 3-42 (S). Simplified Schematic of FLAF Circuit (U)

so that changes in bias, filament, and plate voltage have little effect on the function height.

The FLAJ circuit will desensitize to half-height function with a 3-millivolt interfering signal. If the interfering signal is 5 millivolts or more, however, it will dud completely. The recovery time, or more specifically the limit in number of feet of travel, for removing the interfering signal just before functioning is dependent on the magnitude of the interfering signal. For instance, a 17-millivolt interfering signal requires 200 ft of travel for recovery; a 350-millivolt signal requires 400 ft.

3-1.5.13 (S) Summary of Integrating Amplifier Characteristics

Table 3-1 is a summary of amplifier characteristics discussed in the previous paragraphs. The column headed "Signal Ratio" gives the range of signal amplitudes over which the amplifiers will produce approximately constant burst height. These amplitude variations might

TABLE 3-1 (S). Summary of Integrating Amplifier Characteristics (U)

Amplifier	*Fuze*	*Circuit*	*Signal Ratio for "Constant" Height*	*CCM Qualities CW Sweep Jammer*
PTTB	T766 (Bomb)	Variable Det. Diff.-Limiter Integrator	2:1	1. Cannot prefunction 2. D-factor 400 for dudding
FLAH	T750 (Bomb)	AGC-Det. Variable Integrator	10:1	1. Cannot prefunction 2. D-factor 200 for dudding (assumed)
FLAF	T2031E1 (Rocket)	AGC-Limiter Diff.-Integrator	4:1	D-factor = 200,000 for functioning (approx.)
FLAJ	T293 (Mortar)	AGC-Det. Diff. Integrator	8:1	D-factor = 200,000 for functioning (assumed)

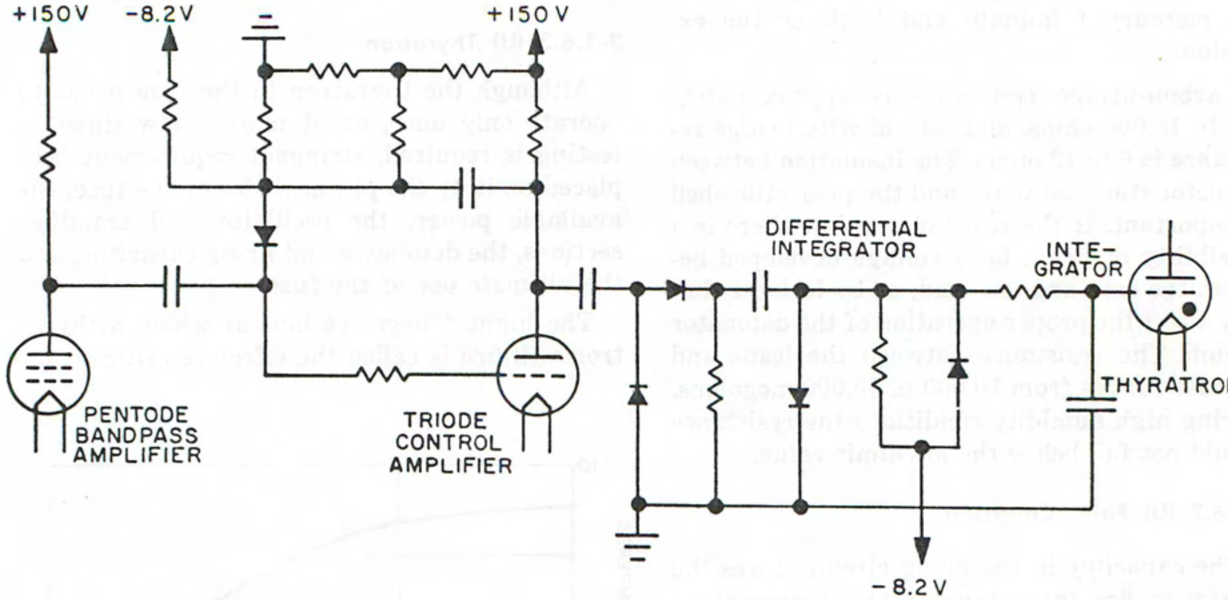

Figure 3-43 (S). Simplified Schematic for FLAJ Circuit (U)

be due to variations in target reflection coefficient, oscillator sensitivity, or to antenna pattern orientation. The D-factor is a measure of fuze ability to reject a jamming signal. It is the ratio of the power required to jam the fuze compared with the fuze output power.

3-1.6 (U) FIRING CIRCUITS (Ref. 16)

The purpose of the fuze firing circuit is to detonate the missile warhead at the proper instant. The firing circuit for a typical CW Doppler fuze consists basically of a thyratron, a capacitor, resistors, and a detonator. The thyratron, capacitor, and detonator are connected in series.

The detonator is fired by discharging the capacitor through the detonator bridge wire. The thyratron is used as the electronic switch to discharge the capacitor through the detonator. Bias for the thyratron is set so that it will fire when a proper signal from the amplifier is applied to its grid.

To prevent the firing circuit from functioning prematurely, both electrical means and mechanical means are used to make it inoperable before arming. In the unarmed state the detonator bridge is not connected to the circuit, and no current can flow through it regardless of what happens to the fuze. Also before arming, the detonator is positioned out of line with, and isolated from, the explosive train. Should the detonator explode, the resulting shock wave will not be great enough to initiate the explosive train.

3-1.6.1 (U) Electrical Detonator

There are two basic types of electrical detonators: the carbon-bridge and the wire-bridge. Both types are used in present fuzing systems. The one used depends on the requirements and characteristics of a particular fuze. Detailed information on construction, performance characteristics, and other pertinent details is given in Reference 1 and in Chapter 9 of this handbook.

Detonators commonly used in fuzing systems have three elements assembled in one container: an upper (spot) charge of lead styphanate or lead azide; an intermediate charge of lead azide; and a lower (base) charge of PETN. This construction permits a very compact assembly for the explosive powder train leading to the tetryl booster charge. The bridge, when heated electrically, supplies the energy to ignite the mercury fulminate and initiates the explosion.

Carbon-bridge resistance is approximately 750 to 15,000 ohms, and typical wire-bridge resistance is 6 to 12 ohms. The insulation between the detonator lead wires and the projectile shell is important. If the resistance is low there is a possibility of firing by a voltage developed between the case and one lead, or by leakage that may affect the proper operation of the detonator circuit. The resistance between the leads and the case ranges from 10,000 to 50,000 megohms. During high humidity conditions the resistance should not fall below the low-limit value.

3-1.6.2 (U) Firing Capacitor

The capacitor in the firing circuit stores the energy to fire the detonator and represents a very low impedance power source. When the thyratron is triggered, the effect is the same as placing a resistor of approximately 18 ohms across the capacitor. For a given capacity, the firing capacitor must be very small physically because of the limited space in the fuze. Paper capacitors are usually used for this purpose. Other capacitors such as mylar, Teflon, and polystyrene, however, are available for special applications. Electrolytic capacitors are unsatisfactory for this application.

The effectiveness of the firing circuit capacitor is determined by its capacitance, inductance, and internal series resistance. For a single discharge, the dielectric absorption is negligible in paper capacitors. One type of test that can be performed to determine the effect of inductance and series resistance on capacitor discharge is to charge the capacitor to approximately 135 volts d.c. and then discharge it through a 15-ohm resistor. The peak current must be at least seven amperes. If either the series resistance or series inductance is excessive the peak current will be lower than this value. The effect of series inductance on peak current is shown in Figure 3-44. A 1.5 microfarad capacitor was used for obtaining the data.

The time lag for current buildup has a bearing on the overall fuze function. The effect of series inductance on the time to reach peak current is shown in Figure 3-45. Other effects of series inductance are given in Reference 1.

3-1.6.3 (U) Thyratron

Although the thyratron in the fuze needs to operate only once, or at most a few times if testing is required, stringent requirements are placed on it by the physical size of the fuze, the available power, the oscillator and amplifier sections, the detonator and firing capacitor, and the ultimate use of the fuze.

The highest negative bias at which a thyratron will fire is called the effective critical gr

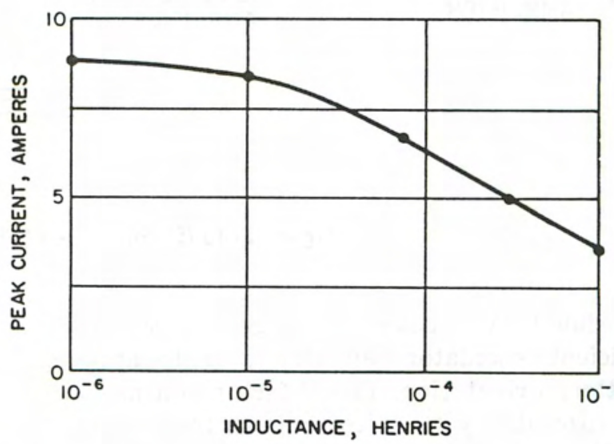

Figure 3-44 (U). Effect of Series Inductance on Peak Surge Current of Firing Capacitor

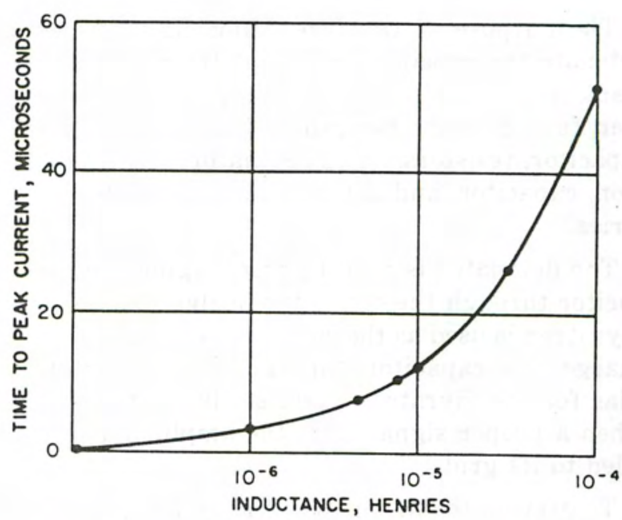

Figure 3-45 (U). Effect of Series Inductance on Time-to-peak Surge Current of Firing Capacitor

voltage. The critical grid voltage of the thyratron should be as insensitive as possible to change in operating voltage, both from the standpoint of magnitude and the ability of the grid to maintain control.

Required surge characteristics are determined by the properties of the detonator and firing capacitor. After triggering, the thyratron must be able to pass peak surge currents of approximately 7 amperes in 0.001 sec. This is necessary so the burst will take place as close as possible to the point in space at which the triggering signal is received. Because of the high speed of most missiles, the time to pass the peak current must be exceedingly short.

Direct-current leakage between plate and grid contributes to unstable critical grid voltages and must be minimized. The insulation resistance between the plate and grid should be of the order of 1,000 megohms. When RC arming is used in addition to mechanical arming, d-c leakage between plate and filament becomes a factor and must also be minimized. Since the tube is subjected to shock and vibration during operation in a missile, it must be mechanically rugged to prevent premature operation due to electrode movement.

As already mentioned, the thyratron need operate only once in fulfilling its mission; nevertheless, it generally undergoes a certain amount of testing prior to use, and must retain a sufficient amount of reserve emission to assure proper operation after testing.

3-1.6.4 (U) Firing Circuit Operation (Ref. 1)

After a missile is launched or released, the sequence of events in the fuze is such that it is ready to operate as soon as arming is completed. To complete arming, an arming switch connects the detonator bridge in a typical firing circuit (Figure 3-46) in series with the firing capacitor and the thyratron. A positive voltage step is applied to the thyratron plate by this switching action. The amplitude of the voltage pulse induced on the thyratron grid is in the ratio of grid-to filament impedance to plate-to-filament impedance. To prevent this pulse from triggering the thyratron, a capacitor is connected from grid to ground. Once the fuze is armed, a positive signal of sufficient amplitude applied to the thyratron grid will fire the thyratron, discharging the firing capacitor through the detonator, and thus initiating the explosion.

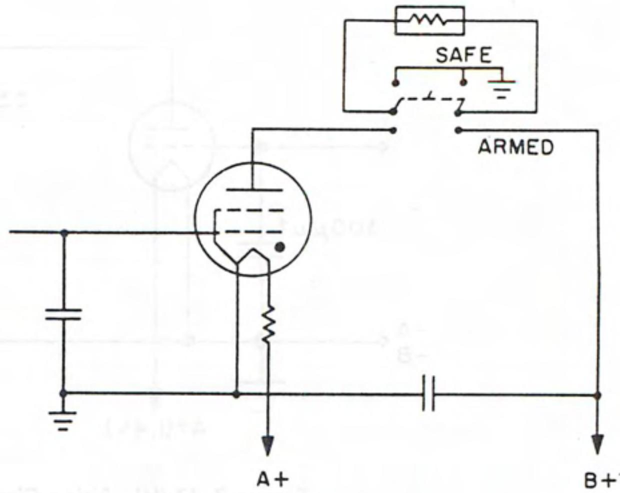

Figure 3-46 (U). Basic Firing Circuit

3-1.6.5 (U) RC Arming

After mechanical arming has occurred, a delay in electrical arming can be provided by using a resistance-capacitor network in the high voltage line in series with the firing capacitor. When mechanical arming is completed the firing capacitor begins charging. The fuze cannot operate until the potential on the firing capacitor is high enough to set off the detonator if the thyratron should fire. The firing capacitor is permanently shunted by a very large safety resistor so that no charge can build up on the capacitor prior to mechanical arming. An RC arming circuit for a fuze is shown in Figure 3-47. A detailed discussion of RC arming is given in Chapter 8 of this handbook.

3-1.6.6 (U) Time Delay

There is a finite time delay between application of the triggering signal on the thyratron grid and the firing of the detonator. This delay is due almost entirely to the detonator. A typical value of the delay is approximately 1 millisecond. The delay in the thyratron is usually less than 150 microseconds, and in the capacitor discharge circuit is less than 60 microseconds. Since one millijoule of energy dissipated in the detonator in one millisecond will set it off, the

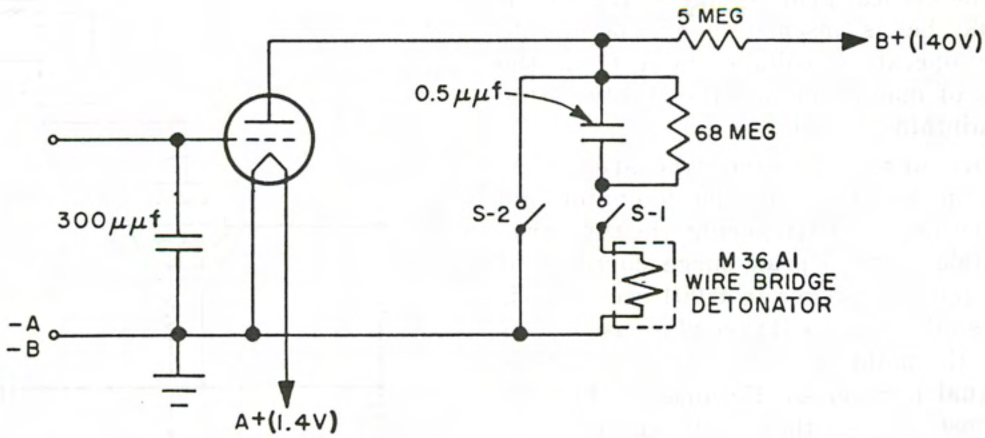

Figure 3-47 (U). Firing Circuit for a Fuze, Showing RC Arming

time delay in this case could be decreased by dissipating more energy in less time in the detonator. For instance, the 1 millisecond delay could be reduced by a factor of 5 by dissipating 3.6 millijoules through this detonator in that time.

3-1.6.7 (U) Component Selection for Firing Circuits

To determine if a given capacitance value can fire a detonator, a capacitor of this value is used to fire detonators in test firing circuits. Initially, the capacitor is charged to a potential that is too low to set off the detonator when the thyratron is triggered. The potential on the capacitor is gradually increased until the detonator fires. By causing several thyratrons, detonators, and capacitors, the spread in firing voltage due to variations in these components is determined. From these data the minimum capacitance needed to fire the detonator can be found.

The firing circuit must be capable of operating over a wide temperature range, normally —65° to 160°F is specified. Low temperatures tend to decrease the available filament and plate voltages.

The lowered filament voltage is advantageous. The decreased filament emission increases the thyratron delay by an insignificant amount. But the lower filament operating temperature results in less filament resistance. The decreased series resistance permits a greater portion of the capacitor energy to be dissipated in the detonator. Typically, about 40% of the energy in the capacitor is transferred to the detonator.

3-2 (S) PULSED DOPPLER FUZING (Refs. 17, 18)

(S) The pulsed Doppler fuze is a refinement of the conventional CW Doppler fuze (paragraph 3-1). There are two types of pulsed Doppler fuzes: self-pulsed Doppler (SPD) and modulated-pulsed Doppler (MPD). The self-pulsed oscillator used in the SPD fuze system is of the squegging or intermittent type. Squegging is dependent on the relative grid-circuit and tank-circuit time constants of the RF oscillator. The MPD oscillator is pulsed with a separate modulator designed to give the desired RF output characteristics.

The advantages of pulsed Doppler operation are:

(a) High peak power output with low average power supply drain.

(b) Good control of burst height by varying pulse width (range cutoff).

(c) High countermeasures resistance as a result of range cutoff.

High countermeasures resistance to repeater jamming is probably the greatest advantage of the pulsed Doppler fuze. Present practical repeater jammers in the VHF range are pulsed to permit time sharing of the receiving and transmitting functions. When the jammer is located beyond the cutoff distance of the pulsed

Doppler fuze, the fuze is as blind to the jammer as it is to a distant target. Therefore, the repeater jammer must receive, amplify, and retransmit the fuze signal before the fuze oscillator is turned off. A repeater jammer can prefunction the fuze only when the fuze is within the upper range cutoff distance from the jammer. By setting this distance to approximately the desired function height, repeater jammer prefunctions become highly improbable. In addition, repeater jammers are not highly effective at close range because they incorporate intentional time delay between receiving and transmitting. When the range is such that the jammer energy reaches the fuze during a succeeding fuze oscillator transmission, however, some jamming is possible.

A CW jammer can induce a signal in pulsed Doppler detectors. Two factors, however, tend to reduce the potency of the jammer. First, the high peak radiated power of the fuze drastically limits the effect of the jammer. Second, a highly discriminating amplifier (integrating amplifier, paragraph 3-1.5.6) can be used in pulsed Doppler fuzes.

3-2.1 (S) BASIC OPERATION

Except for making the RF oscillator squeg (SPD) or adding a pulse modulator (MPD), the pulsed Doppler oscillator consists of the same elements as the conventional CW Doppler fuze. Operation during any given pulse is essentially the same as that of the CW Doppler fuze except that a repetition rate diode detector is used.

Figure 3-48 illustrates the principal waveforms for the pulsed Doppler fuze. The oscillator generates a series of short pulses, the width and repetition of which are controlled by certain oscillator time constants or by the pulse modulator. Any signal reflected from a target is applied to the oscillator grid. Relative motion between the fuze and target causes the amplitude of the pulse on the grid to vary in a Doppler manner.

The pulsed Doppler fuze is quite different from the conventional pulse radar. In pulse radar, a pulse is transmitted, the transmitter is turned off, and a receiver is turned on to receive the return pulse from a target. In the pulsed Doppler fuze, however, the time of reception is during the transmission period because the RF oscillator detects signals efficiently only while it is oscillating. Hence, if the first part of the transmitted pulse from the fuze does not travel the distance to the target and back before the pulse is completed, the fuze does not detect the presence of the target. This characteristic of the pulsed Doppler system results in an upper range cutoff, because for a given pulse duration there is a finite distance beyond which a target-return signal cannot be detected. This upper range cutoff characteristic provides additional height information that the fuze can use. By proper selection of pulse width, the range cutoff point may be positioned at any desired height above the target, and can be used to set the fuze function height. The pulse shapes that are generated, radiated and returned from a target are far from ideal, however, which results in some degradation of the height determination accuracy. Also, there are practical limitations in generating short pulses and in recovering information from very short pulses. This establishes a lower pulse-width limit and, consequently, a minimum height cutoff.

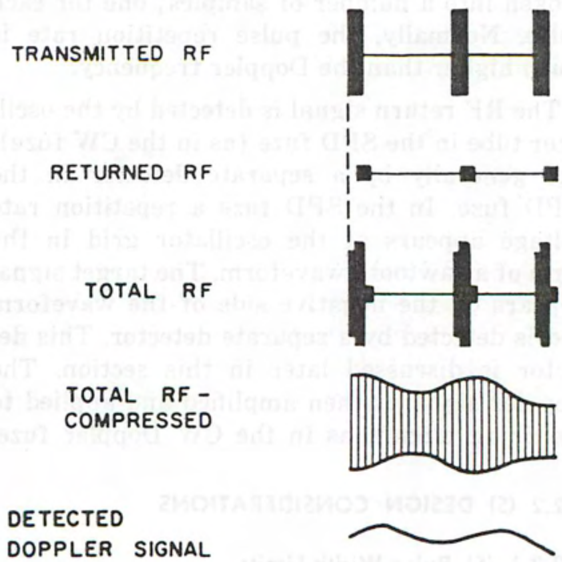

Figure 3-48 (U). Pulsed-Doppler Fuze Waveforms

In the pulsed Doppler fuze, as in the CW fuze, the Doppler signal appears as a modulation on the RF carrier. The Doppler cycle, however, is broken into a number of samples; one for each pulse. Normally, the pulse repetition rate is much higher than the Doppler frequency.

The RF return signal is detected by the oscillator tube in the SPD fuze (as in the CW fuze), and generally by a separate detector in the MPD fuze. In the SPD fuze a repetition rate voltage appears at the oscillator grid in the form of a sawtooth waveform. The target signal appears on the negative side of the waveform and is detected by a separate detector. This detector is discussed later in this section. The Doppler signal is then amplified and applied to the firing circuit, as in the CW Doppler fuze.

3-2.2 (S) DESIGN CONSIDERATIONS

3-2.2.1 (S) Pulse Width Limits

Neglecting practical modifying factors, the minimum pulse width is determined by the maximum function height desired, because the signal must have time to reach the target and be reflected back to the fuze during each pulse period. Thus, if T is the pulse width

$$T \geqq \frac{2h_o}{c}$$

where

h_o = maximum desired function height

c = velocity of propagation of the RF signal (3×10^8 meters per second)

The use of extremely narrow pulses leads to difficulty in detection and the need for extremely low circuit Q.

To determine maximum pulse width, changes in Doppler signal amplitude and the effects of repeater jamming may be considered. The pulse should be narrow enough so that the Doppler amplitude does not change appreciably during the time that it is being sampled by the pulse. The voltage being sampled, E, is assumed to be sinusoidal or

$$E = E_o e^{iw_d t}$$

where

E_o = maximum value of E

$w_d = 2\pi f_d$

e = base of Naperian logarithm

$i = \sqrt{-1}$

t = time in seconds

and

$$f_d = \frac{2vf_o}{c} \tag{3-6}$$

where

f_d = Doppler frequency (cps)

v = velocity of fuze relative to target (meters per second)

f_o = oscillator frequency (cps)

Differentiating to obtain the voltage change with respect to time

$$dE = E_o i w_d e^{iw_d t} dt$$

and taking the maximum value of dE, to obtain the maximum rate of change E

$$dE = E_o w_d dt$$

Substituting the pulse width T for dt, ΔE for dE, and combining with Equation 3-6

$$\Delta E = \frac{4\pi E_o v f_o T}{c}$$

or

$$\frac{\Delta E}{E_o} = \frac{4\pi v f_o T}{c} \tag{3-7}$$

This is the relation among the percentage change in E, the Doppler frequency, and the pulse width. If ΔE is less than 5% of E_o, the voltage during the pulse is practically constant. Therefore, by arbitrarily choosing $\Delta E/E_o$ to be less than 0.05, and solving Equation 3-7 for T, the restriction on the pulse width is

$$T \leqq \frac{0.05c}{4\pi v f_o}$$

When considering the effect of repeater jamming, the time Δt, for the fuze transmitted signal to reach the jammer and be returned, plus the time delay within the repeater itself, limits the maximum pulse width. If Δt exceeds T, a repeater jammer signal canot prefunction the fuze since the fuze can detect a signal only during its on-time. Thus, the maximum pulse width is defined as

$$T \leqq \Delta t = \frac{2R}{c} + \delta$$

where

R = distance from fuze to repeater

δ = inherent delay in repeater

If R does not exceed maximum function height, h_o, a repeater jammer cannot prefunction the fuze except under special conditions.

Experiments indicate that, at VHF, repeater jammers that simply pick up, amplify, and immediately retransmit the fuze signal tend to go into self-oscillation under high-sensitivity conditions. This makes high-power jammers of this type somewhat impractical, and the emphasis in countermeasure work has been devoted to repeaters of the gated delay type. In a typical gated delay repeater, delay, δ, between the time the signal is received and time at which it is retransmitted is from a few microseconds to a few milliseconds. Hence, if a pulse width of about two microseconds or less is used in the pulsed Doppler system, the returned pulse from such a repeater jammer cannot interact with the initiating pulse at the fuze, even at short jammer-to-fuze range. Random interaction of the repeater jammer on succeeding fuze oscillator pulses is possible, however.

3-2.2.2 (S) Repetition Rate Limits

Because the pulsed Doppler fuze is essentially a sampling device, the number of pulses, or samples, required to convey information to reconstruct the Doppler frequency must be considered. Referring to Figure 3-49, if three pulses are equally spaced over the first half-cycle; one at the start, one at the peak, and one at the end, a curve is defined. For the second half-cycle, a pulse at the peak and another at the end of the cycle define a curve that, when connected with the first half-cycle, gives the minimum representation of a complete cycle of a sine wave. Therefore, as shown in Figure 3-49, the minimum time between pulses must not exceed one-quarter of the period of the sine wave. This is expressed by

$$T_R \leq \frac{T_D}{4}$$

where

T_R = time between pulses

T_D = period of sine wave

As the number of pulses is increased, the sine wave is more accurately reconstructed.

By combining $T_R \leq \frac{T_D}{4}$ with Equation 3-6, the maximum permissible time between pulses can be related to the fuze oscillator frequency

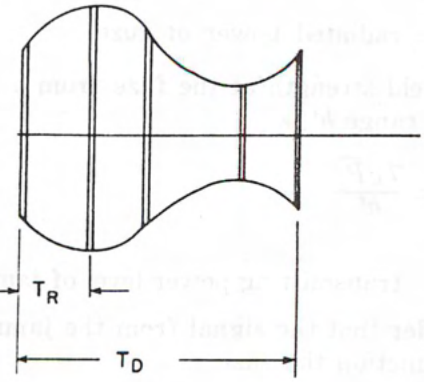

Figure 3-49 (U). Doppler Signal Reconstruction

and fuze velocity relative to the target. This is expressed by

$$T_R \leq \frac{c}{8vf_o}$$

where

c = velocity of propagation of RF signal (3 x 10^8 meters/second)

v = velocity of fuze relative to target (meters/second)

f_o = oscillator frequency (cps)

The effects of repeater jamming must also be considered when determining the time between pulses for a pulsed Doppler fuze. As discussed in paragraph 3-2.2.1, the maximum pulse width should be less than the time required for the fuze signal to reach the jammer and be transmitted back. The possibility exists, however, that the jammer could return a pulse during the next transmitting period of the fuze, unless the fuze repetition rate is jittered. The range at which this jamming occurs is

$$h' = \frac{cT_R}{2}$$

In considering the effect of this jamming signal, only orders of magnitude are of interest for a first approximation. Therefore, half-wave dipoles are considered as the fuze and jammer antennas. With this assumption, the maximum field strength at the fuze from its own reflected signal, E_f, at function height, h_o, is given by

$$E_f = \frac{7\sqrt{P_f}}{2h_o} \tag{3-8}$$

where

$P_f =$ radiated power of fuze

The field strength at the fuze from a jammer, E_j, at range h' is

$$E_j = \frac{7\sqrt{P_j}}{h'} \quad (3\text{-}9)$$

where

$P_j =$ transmitting power level of jammer

In order that the signal from the jammer does not function the fuze

$$E_j < E_f \quad (3\text{-}10)$$

Combining Equations 3-8, 3-9, and 3-10

$$\frac{\sqrt{P_j}}{h'} < \frac{\sqrt{P_f}}{2h_o}$$

and

$$\sqrt{\frac{P_j}{P_f}} < \frac{h'}{2h}$$

3-2.2.3 (S) Pulsed Doppler Detectors

The detection system for the pulsed Doppler fuze presents a problem that differs from that of the conventional CW Doppler fuze. The grid voltage output of either a SPD or MPD oscillator is a series of pulses of one type or another. If the fuze is moving toward or away from a target, the amplitude of the grid pulses will vary slightly with distance at a Doppler rate. The changes in amplitude between the minimum and maximum peaks of the Doppler cycle, however, are very small compared with the total pulse amplitude, even when the target is as close as a few wavelengths.

For example, assume a 150-mc RGD fuze oscillator with a sensitivity of 20 volts and a free-space grid voltage of 70 volts. If the fuze is at a mean height of 100 ft above a perfect reflector and moves through a distance of $\lambda/2$ relative to the reflector, the change in grid voltage would be only 0.35 volt peak-to-peak. This change is only one-half percent of the total grid voltage and may be considered as the percentage of modulation of the pulses due to the reflected signal. To recover the Doppler frequency, the pulses would have to be demodulated in some manner to properly recover the amplitude changes of the pulses. While this can be done using an oscillator-detector system, it is more feasible to use a separate detector that rectifies the RF and removes most of the unwanted pulse signal at the same time.

For several reasons it is desirable that the pulsed Doppler fuze detector be sensitive only to the peaks of the pulses. The use of a peak signal detector requires that the amplitude of any between-pulse interference be comparable with that of the puse, in order to appear at the detector output. Further, the variation of the target signal ampliude with range would be altered from that of the typical proximity fuze signal, if the output were proportional to the average instead of the peak of the signal.

The maximum degree of peak detection in a simple circuit is limited by the amplitude and frequency of the Doppler signal received. The detector output must decay enough between pulses to be responsive to the changing Doppler amplitude. Furthermore, the higher the Doppler frequency in relation to the pulse repetition rate, the more difficult is the filtering. The percentage of repetition-rate ripple in the detector output is a measure of the degree of peak detection. Table 3-2 shows the effect of diode load resistor (degree of peak detection) on the sensitivity, noise, and ripple voltage of the pulsed Doppler oscillator.

There are other detection systems that can be used. A vacuum-tube diode in either the plate or grid circuit could operate as a combined RF and repetition-rate detector. A diode at the plate should give a higher output signal than the grid-cathode detector. Vacuum-tube diodes, however, introduce practical difficulties because of the need for aboveground filaments in these circuits.

3-2.2.4 (C) Pulsed Doppler Fuzes

The following paragraphs briefly discuss a typical SPD and a typical MPD fuze. The MPD system described was strictly an experimental model to prove the feasibility of the MPD system.

3-2.2.5 (C) SPD Fuze System

The general arrangement of a typical SPD fuze system is similar to that of a normal CW

TABLE 3-2 (S). Effect of Diode Load Resistor (U)

Diode Load Resistance (megohms)	*DC Diode Voltage (volts)*	*Peak-Peak Ripple (volts)*	*Noise (mv-rms)*	*Sensitivity (volts)*	*Sensitivity-to-Noise Ratio*
15	76	0.75	1.25	15.2	12,100
6	73	1.5	1.4	14.9	10,600
3.7	69	2.2	1.6	14.5	9,100
2.3	68	2.8	1.8	14.2	7,900
0.95	66	5.7	2.3	13.5	5,900
0.45	64	11.0	3.2	13.4	4,200
0.22	55	17.0	4.5	11.7	2,600

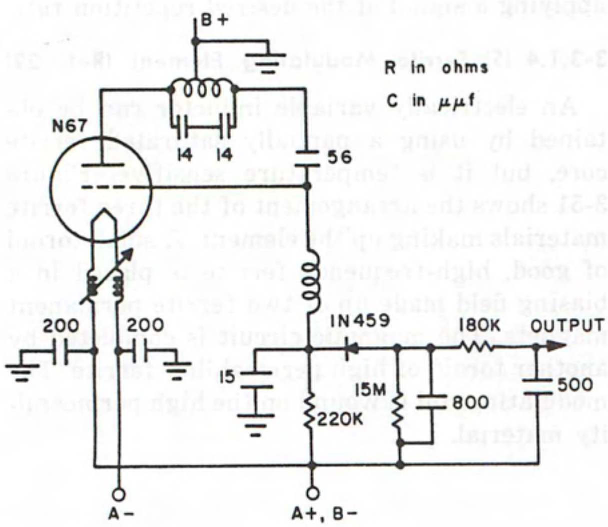

Figure 3-50 (C). SPD Oscillator-detector (U)

Doppler fuze system. The basic difference is that the SPD system uses a pulsed RF oscillator and peak detector (Figure 3-50). The pulsing RF oscillator is sensitive to changes in antenna loading during the time of pulse transmission. The grid-filament circuit of the oscillator operates as an RF detector, and converts amplitude variations of the RF signal into amplitude variations at the pulse repetition rate. A second detector, responsive approximately to the peak of its input, recovers the Doppler-frequency signal from the amplitude variation of the repetition-rate signal. An amplifier increases the amplitude of the resultant signal to a level sufficient to trigger a thyratron firing circuit.

3-2.2.6 (C) MPD Fuze System

Prior to the development of a successful SPD fuze, pulsed Doppler fuzes with separate pulse modulators were investigated. Several types of pulse modulators were tried (Ref. 20). A thyratron pulse generator with resistance charging proved reasonably successful. In the experimental models, a vacuum-tube diode peak detector was used to recover the Doppler signal. At the time of the investigations, suitable semiconductor diodes were not available. Design data for this fuze are given in Reference 18.

3-3 (S) FREQUENCY MODULATED FUZING (Ref. 21)

(S) Frequency modulated radio proximity fuzes are particularly attractive for guided-missile applications. Frequency modulation (FM) overcomes the problem of microphonics resulting from the severe vibration encountered in guided missiles. Also, FM permits shaping of the range law so that the fuze can discriminate against signals reflected from parts of the missile body from the ionized exhaust of the missile and against microphonically modulated reflections in the fuze RF transmission system.

FM fuzing systems now in use operate in the microwave region, because of problems in obtaining the required frequency deviation with the components available for VHF/UHF operation. At X-band, klystrons readily provide the required frequency deviation. The most important parameter in fuze design is the absolute frequency deviation, not the percentage deviation, and, in general, it is difficult to obtain a high percentage of deviation. Therefore, as the center frequency of the fuze RF oscillator is lowered, with the absolute deviation remaining constant, deviating the oscillator frequency becomes more difficult.

There are several advantages of VHF/FM over microwave FM. The primary advantages are higher efficiency, smaller and lighter equipment, and the capability of operating at higher power output. The last advantage results in higher countermeasures resistance, because additional jamming power is required to jam the fuze. Because VHF antenna patterns are relatively broad when compared to microwave antenna patterns, however, the VHF/FM fuze, can be jammed over a wider angle than the microwave FM fuze. In some applications it may be desirable to have uniform coverage over a rather large angle, in which case VHF operation is definitely superior.

By operating FM fuzes in the VHF as well as in the microwave region, fuze frequencies can be distributed over a greater portion of the RF spectrum. This is a decided counter-countermeasures advantage because it would require enemy jammers to cover a greater frequency range.

3-3.1 (S) Possible Methods of Obtaining Frequency Deviation at VHF

(U) The space, weight, and power limitations of a fuze present design problems in obtaining the required FM. Some of the possible methods for frequency modulating fuze RF oscillators are discussed below.

3-3.1.1 (C) Reactance Tube

The reactance tube supplies a reactive current to the oscillator tank that is several times the a-c current supplied by the oscillator tube. Although this reactive current represents no real power to the oscillator tank it requires a rather large power tube to supply it. Also, nonlinear deviation and large incidental amplitude modulation are produced at wide deviation ranges. Hence, the reactance tube method of modulation has never been seriously considered.

3-3.1.2 (C) Mechanical Systems

There are several ways of producing frequency modulation of an oscillator by mechanical means. No known mechanical system, however, can generate repetition rates above the microphonic region and, furthermore, mechanical systems themselves produce microphonics. Consequently, they are not used.

3-3.1.3 (C) Voltage-sensitive Capacitors (Varactors)

A varactor is a p-n junction semiconductor diode that changes its capacitance as the amplitude of the applied voltage is varied. Frequency modulation can be obtained by using this type of capacitor in the oscillator tank circuit and applying a signal of the desired repetition rate.

3-3.1.4 (S) Ferrite Modulating Element (Ref. 22)

An electrically variable inductor can be obtained by using a partially saturated ferrite core, but it is temperature sensitive. Figure 3-51 shows the arrangement of the three ferrite materials making up the element. A small toroid of good, high-frequency ferrite is placed in a biasing field made up of two ferrite permanent magnets. The magnetic circuit is completed by another toroid of high permeability ferrite. The modulating coil is wound on the high permeability material.

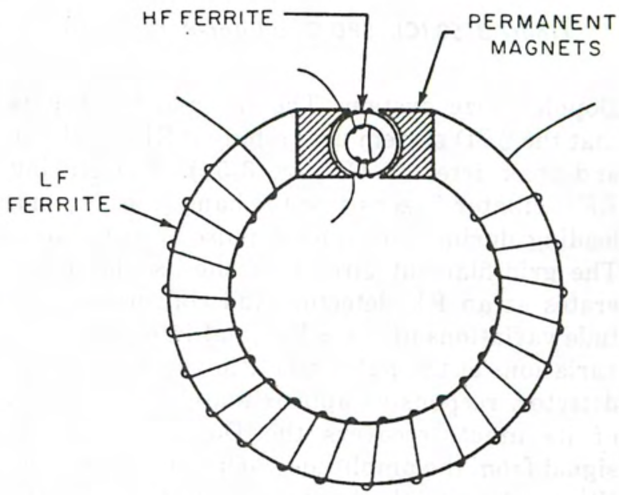

Figure 3-51 (U). Ferrite Frequency-modulating Element

The tank inductance of the RF oscillator is wound on the small toroid, and the inductance is varied by varying the incremental permeability of the ferrite. This is accomplished by partially saturating the high-frequency ferrite in the field produced by the permanent magnets and the low-frequency winding. A typical change in frequency with variation of incremental permeability is shown in Figure 3-52. The permanent magnet bias is chosen to set the operating point at the appoximate center of the linear portion of the frequency characteristic. This assures that the frequency modulation will be a faithful reproduction of the modulating current.

The low-frequency ferrite is quite lossy at high frequencies, so the high-frequency field must be kept out of the low-frequency ferrite to obtain a high-Q tank. The permanent magnets act as an effective air gap between the two ferrite materials, and have a very low loss at VHF.

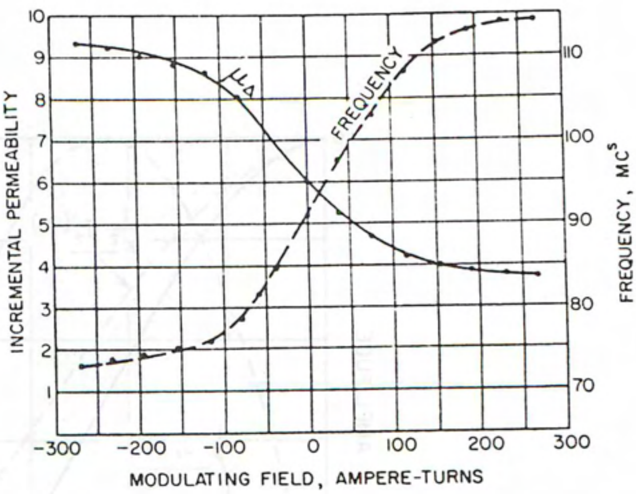

Figure 3-52 (S). Modulation Characteristic of Ferrite Modulating Element (U)

3-3.2 (S) Reduction of Microphonic Effects

To understand how FM reduces the effects of microphonics, consider first the effects of microphonics on CW fuzes. Figure 3-53(A) shows the typical manner in which the Doppler signal is recovered from a CW fuze. The Doppler signal appears as a low-frequency modulation on the RF signal at the oscillator grid. This RF signal is rectified at the grid and the Doppler signal appears across the grid-leak resistor. Any microphonic modulation of the oscillator output also appears at this point. A typical CW Doppler fuze oscillator can generate a 60-volt signal at the grid, which results in 60 volts d.c. at the grid. If a micophonic disturbance produces a 1 percent modulation of the fuze RF carrier, there is a change of 0.6 volt in signal at the grid. The signal from a target must compete with this signal if they are in the same frequency range. By frequency-modulating the fuze RF oscillator at a high repetition rate, however, the Doppler signal can be recovered at a frequency much higher than the microphonic frequencies. This suppresses the effects of the microphonics. As shown in Figure 3-53(B), a tuned circuit is inserted in series with the oscillator grid leak. This circuit is tuned to the repetition-rate frequency or one of its harmonics. Because this frequency is high compared to any microphonic frequencies, the microphonics do not appear across the tuned circuit.

As the RF oscillator is frequency modulated, some amplitude modulation at the repetition rate is produced and appears across the tuned circuit. Assume that 0.1 volt at the repetition rate frequency appears across the tuned circuit because of the amplitude modulation. This signal will also be modulated by the microphonics by the same amount (1 percent) and the RF carrier. Because it has only 1/60 the amplitude of the RF carrier, however, the microphonic signal amplitude will be only 0.01 volt. The desired signal appears as a Doppler-modulated voltage at the resonant frequency of the tuned circuit, and is recovered with little loss if the impedance at resonance of the tuned circuit is made high. Improvements in microphonic noise-to-signal ratios by factors of 200 have been achieved.

3-3.3 (S) Signal Shaping versus Range Characteristics

Frequency modulation produces some shaping of the signal-vs-range characteristic of the fuze, reducing the effect of very close-in targets. Three different cases are illustrated in Figure 3-54. For these curves,

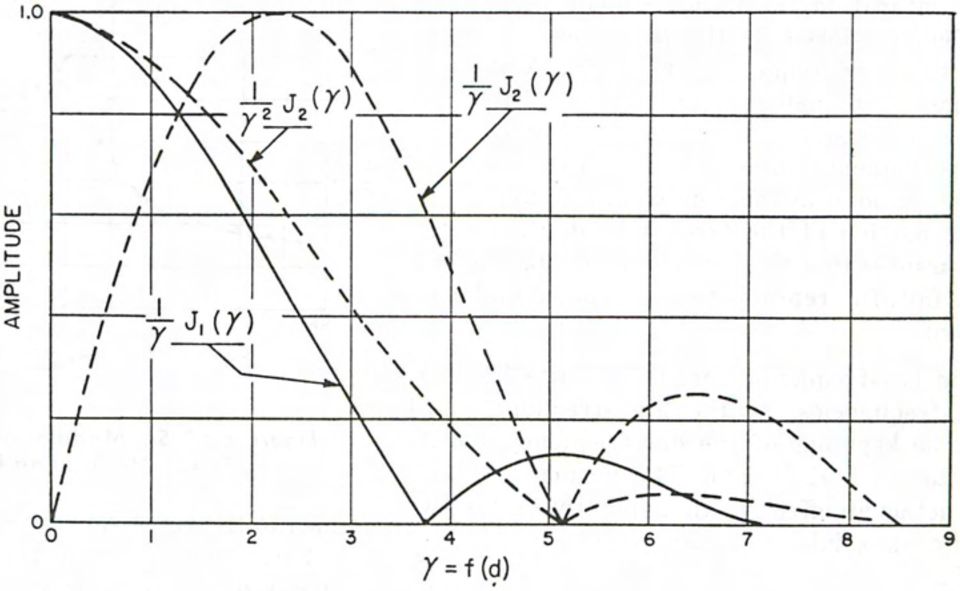

Figure 3-53 (U). Microphonic Reduction Mechanism

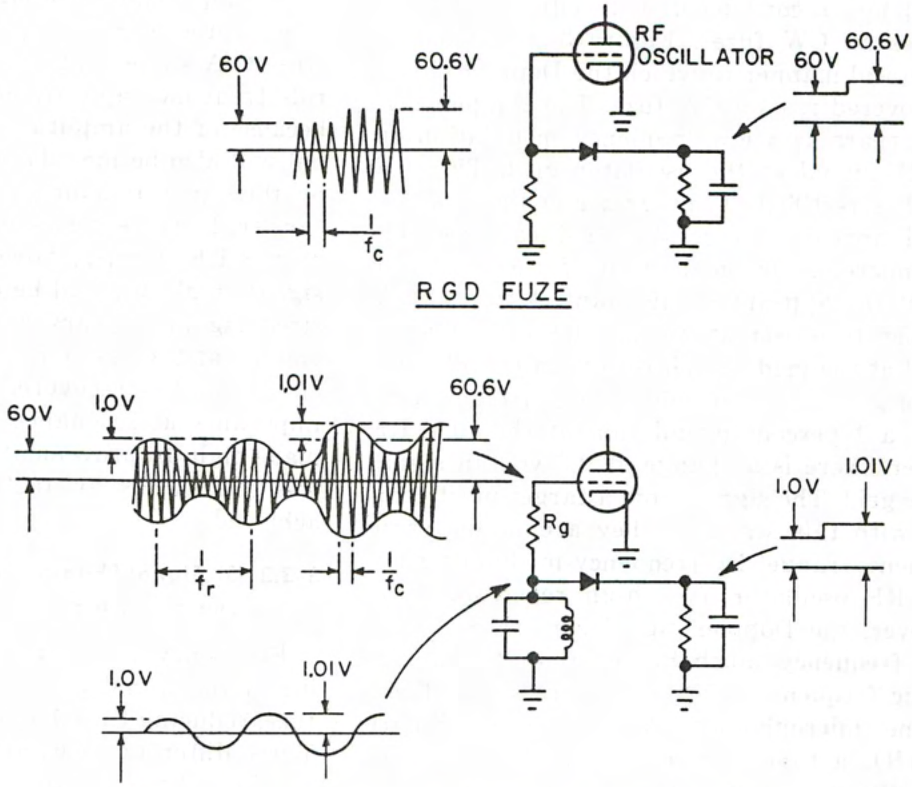

Figure 3-54 (C). Range Characteristics of VHF/FM Fuze (U)

$J_n =$ Bessel function of first kind, order n

$\gamma = (2\Delta F/\mu) \sin \mu\tau$

$\Delta F =$ peak deviation

$\mu =$ modulation frequency

$\tau = \frac{2h}{c} =$ time for signal to reach target and return

The curves labeled $\frac{1}{\gamma} J_1(\gamma)$ and $\frac{1}{\gamma} J_2(\gamma)$ show the trend to be expected in the signal from a fuze approaching a surface target, using the fundamental and the second harmonic of the repetition rate, respectively. In the first case $\frac{1}{\gamma} J_1(\gamma)$, the signal approaches a maximum relative amplitude of 1.0, whereas the signal from a CW fuze follows a hyperbola to small distances from the target and increases beyond the maximum value shown in Figure 3-54.

When the second harmonic of the repetition rate frequency is used, the signal follows the curve labeled $\frac{1}{\gamma} J_2(\gamma)$ and actually falls to zero at zero range.

If the approach is to an air target, the curve labeled $\frac{1}{\gamma^2} J_2(\gamma)$ shows the approximate shape of the signal-vs-range characteristic. This is approximate because for very close targets the signal will actually go to zero since it can no longer be assumed that the target is evenly illuminated by the fuze signal and the target may not be small compared to the range. (The range law for air targets approaches $1/h$ at short ranges.)

3-3.4 (S) Typical VHF/FM System

A block diagram of a typical VHF/FM fuze is shown in Figure 3-55. The recovery circuit and the first amplifier are tuned to the second harmonic, J_2, of the repetition rate. Less amplitude modulation is produced by operating in this mode. The second amplifier, which is a Doppler amplifier, and the firing circuit are the same as those used in the conventional CW Doppler fuze.

3-3.4.1 (S) Modulating Oscillator

The tank coil for the modulating oscillator (Figure 3-56) is wound on the low-frequency ferrite toroid (Figure 3-51). The capacitors across this coil tune it to the required repetition rate. The alternating voltage produced by the oscillator varies the incremental permeability of the ferrite. This, in turn, varies the permeability of the high-frequency ferrite toroid on which is wound the tank coil for the RF oscillator.

3-3.4.2 (S) RF Oscillator (Ref. 22)

The RF oscillator (Figure 3-56) is a conventional Colpitts circuit with the tube and stray capacities tuning the tank to the desired center frequency. The 1,000-ohm resistor in the B+ line reduces the tendency of the oscillator to squeg. The grid circuit, besides the usual grid choke and resistor, contains a circuit that can

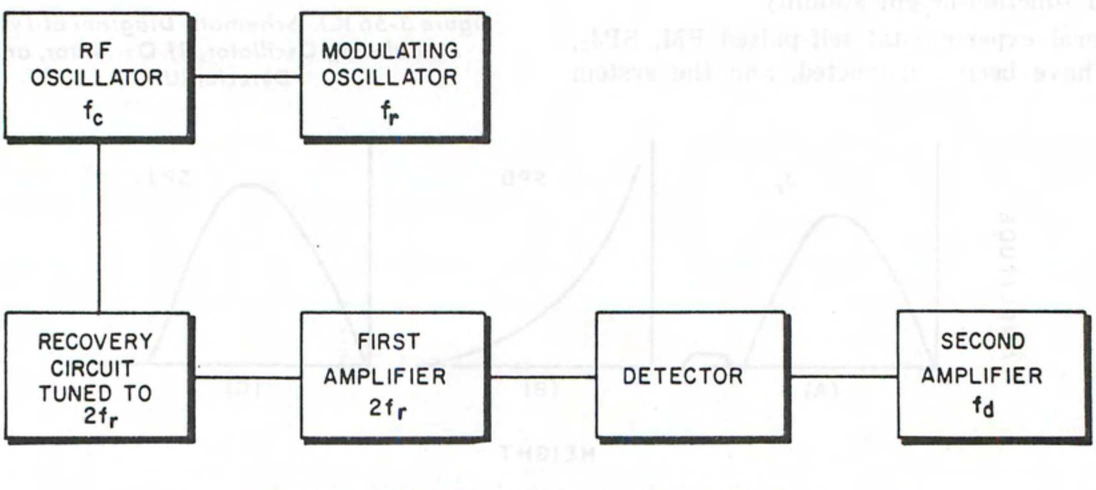

Figure 3-55 (U). Block Diagram of VHF/FM Fuze

be tuned to the fundamental or one of the harmonics of the repetition rate. The change in incremental permeability of the small toroid (Figure 3-51) results in frequency modulation of the RF oscillator by the modulating oscillator.

3-3.4.3 (S) Detector

The detector (Figure 3-56) is a semiconductor diode connected at the junction of the grid resistor and the tuned circuit that is in series with the grid circuit. A resistance-capacitance filter shunts the repetition rate frequency to ground, and the Doppler frequency is fed to the input of the low frequency amplifier.

3-4 (S) PULSED FREQUENCY MODULATED FUZING (Ref. 23)

(S) A simple radio proximity fuze having a high function height can be made by combining the self-pulsed Doppler (SPD) and the CW/FM fuze (J_2). This combination results in a low-noise system with a range law better than that of either fuze by itself. As shown in Figure 3-57, combining results in a range law without the secondary peaks of the Bessel curve characteristic of the J_2 fuze, and with an increased slope over that of the SPD. Furthermore, because of the range law cutoff characteristics of the SPD, the effects of frequency deviation changes for the J_2 fuze can be reduced almost completely to amplitude variations. Another possible advantage is an increase in the slope of the range law that should result in an improved function-height stability.

Several experimental self-pulsed FM, SPJ_2, fuzes have been constructed, and the system

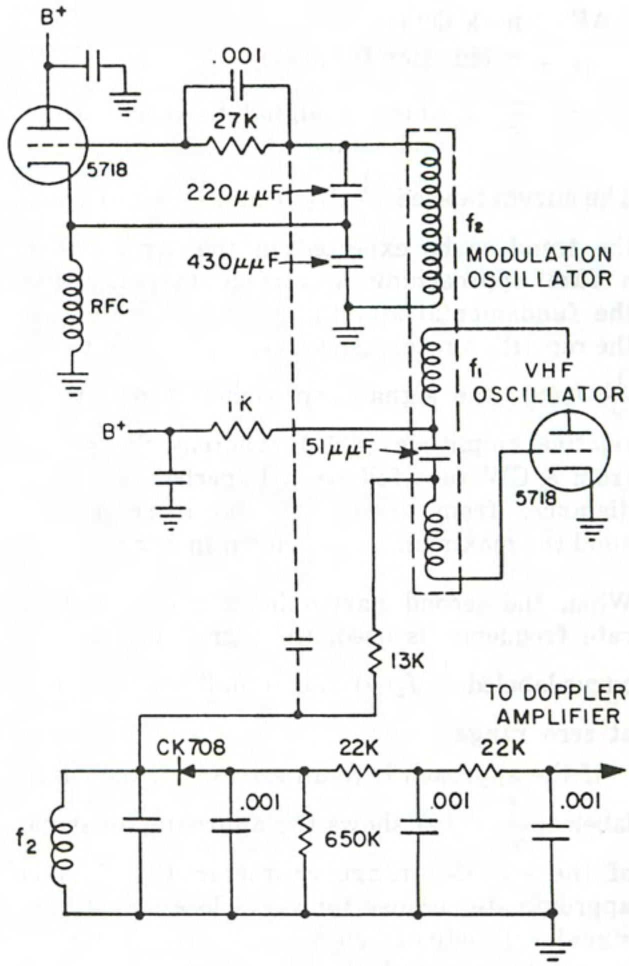

Figure 3-56 (C). Schematic Diagram of Typical Modulating Oscillator, RF Oscillator, and Detector (U)

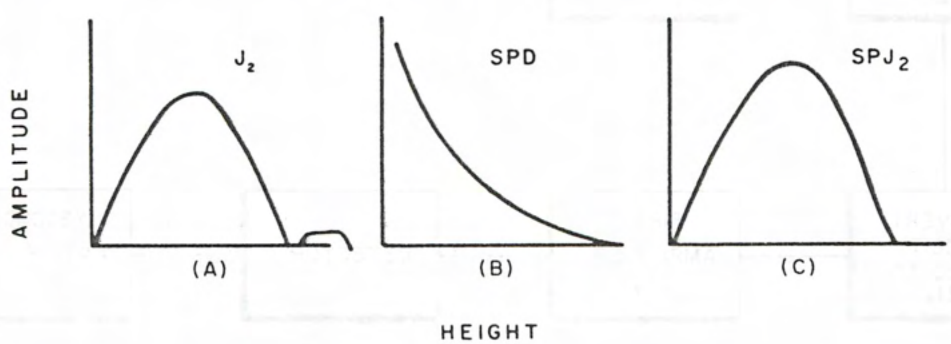

Figure 3-57 (U). Typical Range Law Curves for J_2, SPD, and SPJ_2 Fuze Systems

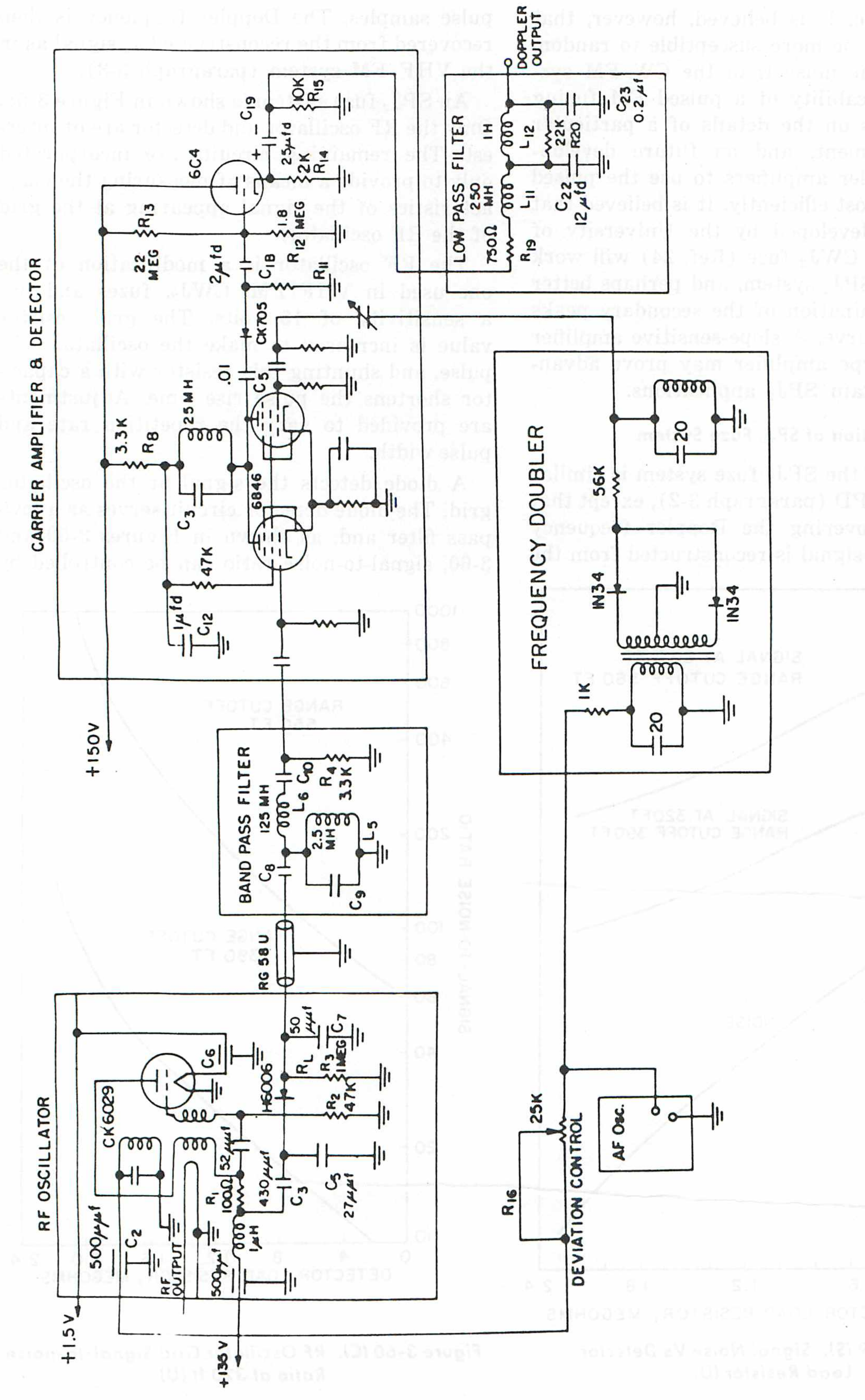

Figure 3-58 (S). Experimental Pulsed VHF/FM (SPJ), Fuze System (U)

appears feasible. It is believed, however, that the system will be more susceptible to random and microphonic noise than the CW/FM system. The applicability of a pulsed FM fuzing system depends on the details of a particular fuzing requirement, and on future developments in Doppler amplifiers to use the pulsed J_2 range law most efficiently. It is believed that the amplifier developed by the University of Florida for the CWJ_2 fuze (Ref. 24) will work as well in the SPJ_2 system, and perhaps better because of elimination of the secondary peaks of the Bessel curve. A slope-sensitive amplifier or a counter-type amplifier may prove advantageous in certain SPJ_2 applications.

3-4.1 (S) Operation of SPJ_2 Fuze System

Operation of the SPJ_2 fuze system is similar to that of the SPD (paragraph 3-2), except that instead of recovering the Doppler frequency directly, the J_2 signal is reconstructed from the pulse samples. The Doppler frequency is then recovered from the reconstructed J_2 signal as in the VHF/FM system (paragraph 3-3).

An SPJ_2 fuze system is shown in Figure 3-58. Only the RF oscillator and detector are of interest. The remaining circuits are incorporated only to provide a means of measuring the characteristics of the signal appearing at the grid of the RF oscillator.

The RF oscillator is a modification of the one used in VHF/FM, CWJ_2, fuzes and has a sensitivity of 15 volts. The grid resistor value is increased to make the oscillator self-pulse, and shunting this resistor with a capacitor shortens the pulse rise time. Adjustments are provided to vary the repetition rate and pulse width.

A diode detects the signal at the oscillator grid. The diode detector circuit serves as a low-pass filter and, as shown in Figures 3-59 and 3-60, signal-to-noise ratio can be controlled by

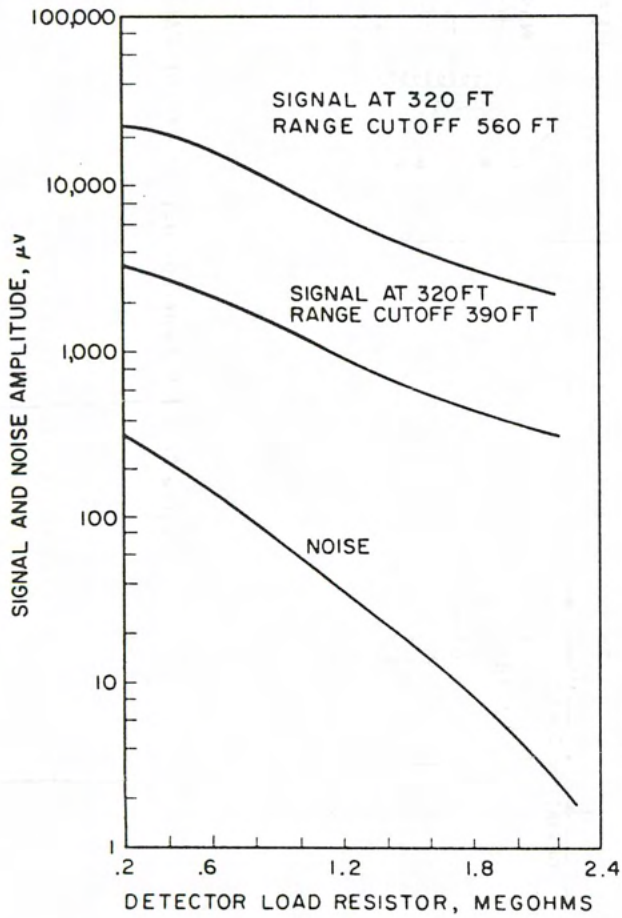

Figure 3-59 (S). Signal Noise Vs Detector Load Resistor (U)

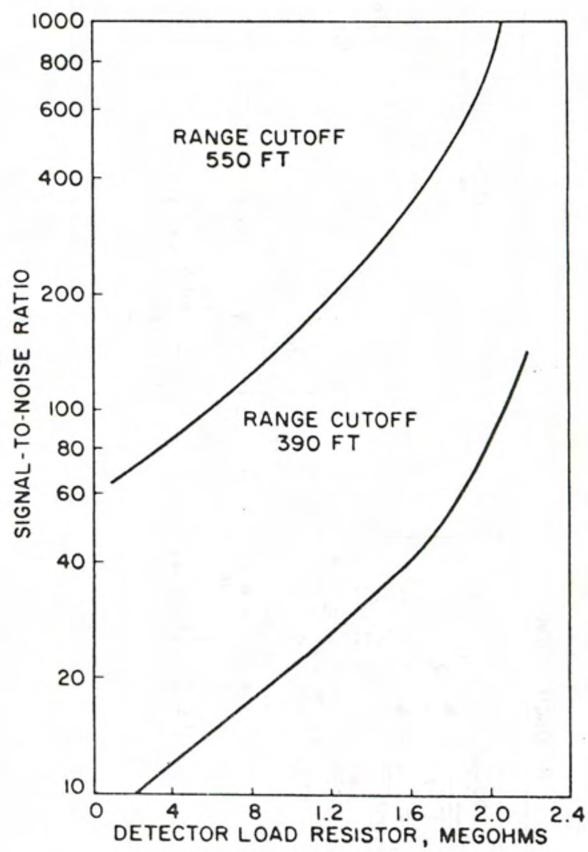

Figure 3-60 (C). RF Oscillator Grid Signal-to-noise Ratio at 320 ft (U)

adjusting the diode load resistor to set the circuit bandpass characteristics.

3-4.2 (S) Design Considerations

(S) The basic problem in the SPJ_2 system is choice of circuit parameters to obtain the required range law and best signal-to-noise ratio. The influencing parameters are the modulating frequency, RF oscillator frequency deviation, pulse width, and pulse repetition rate. The greatest latitude is in the choice of the modulating frequency. The frequency should be high enough to move the selected J term out of the noise spectrum of the RF oscillator, and low enough to permit easy recovery of the J2 signal considering the SPD pulse repetition rate.

3-4.2.1 (S) Pulse Width and Frequency Deviation Signal

The pulse width and carrier frequency deviation directly affect the shape of the range law and are selected for each fuzing application. For high function-height applications the best choice is the one that will give the maximum slope to the resultant range law at the point of range law cut-off distance. A plot of the J_2 and pulse-Doppler range laws (Figures 3-61 and 3-62) indicates that the maximum slope occurs at range cutoff on the SPD and at the Bessel zero for the J_2.

After the height of range cutoff is chosen, the pulse width is specified allowing 1 microsecond pulse width for each 492 ft of distance to the cutoff point. The best correlation results when the pulse width is measured from the base of its leading edge to the top of its trailing edge. It is recommended that a RF delay line range simulator be used to adjust the pulse to the correct width.

The deviation of the RF oscillator necessary to place the zero of the Bessel curve at the desired height can be calculated from the information that follows. The modulation index, δ, of the spectrum at the RF oscillator grid in the presence of a target signal is given by

$$\delta = \frac{2\Delta F}{m} \sin \frac{2\pi d}{\lambda m}$$

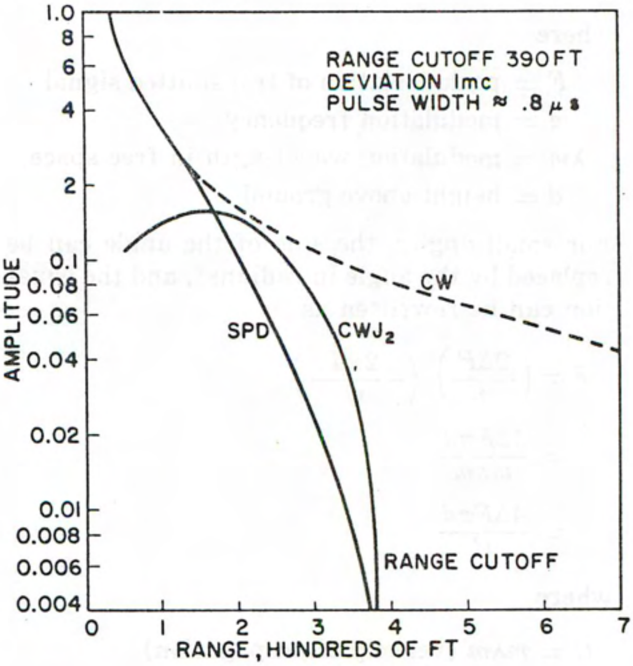

Figure 3-61 (C). Comparison of CWJ_2 and SPD Signal Return from Ground Target (390-ft Range Cutoff) (U)

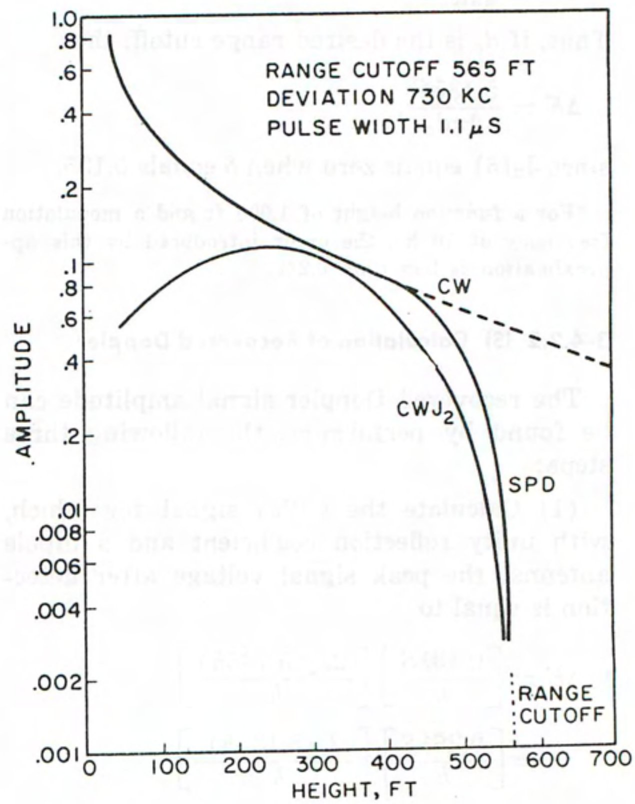

Figure 3-62 (C). Comparison of CWJ_2 and SPD Signal Return from Ground Target (565-ft Range Cutoff) (U)

where

$F =$ peak deviation of transmitted signal
$m =$ modulation frequency
$\lambda m =$ modulation wavelength in free space
$d =$ height above ground

For small angles, the sine of the angle can be replaced by the angle in radians*, and the equation can be rewritten as

$$\delta = \left(\frac{2\Delta F}{m}\right)\left(\frac{2\pi d}{m}\right)$$

$$= \frac{4\Delta F \pi d}{m \lambda m}$$

$$= \frac{4\Delta F \pi d}{C}$$

where

$C = m\lambda m$ (velocity of propagation)

Solving the above equation for ΔF gives

$$\Delta F = \frac{\delta C}{4\pi d}$$

Thus, if d_c is the desired range cutoff, then

$$\Delta F = \frac{5.135C}{4\pi d_c},$$

since $J_2(\delta)$ equals zero when δ equals 5.135.

*For a function height of 1,000 ft and a modulation frequency of 10 kc, the error introduced by this approximation is less than 0.2%.

3-4.2.2 (S) Calculation of Recovered Doppler

The recovered Doppler signal amplitude can be found by performing the following three steps:

(1) Calculate the CWJ_2 signal for which, with unity reflection coefficient and a dipole antenna, the peak signal voltage after detection is equal to

$$\Delta E = \left[\frac{0.13\lambda S}{h}\right]\left[\frac{2J_2(5.135h)}{h_o}\right]$$

$$= \left[\frac{0.26\lambda S}{h}\right]\left[\frac{J_2(5.135h)}{h_o}\right]$$

where

$\frac{0.13\lambda S}{h}$ is the CW Doppler signal

$2J_2\frac{5.135h}{h_o}$ is the J_2 envelope function

$\lambda =$ free space RF wavelength
$S =$ sensitivity of fuze oscillator
$h =$ height above ground
$h_o =$ desired height for range cutoff (height at which $J_2(X)$ has first zero above X equals 0)
$X = 5.135$ for J_2X equals 0

(2) Correct ΔE for the effect of the pulse. The best way at present is on the basis of experimental results of the pulsed Doppler system (Figures 3-63 and 3-64).

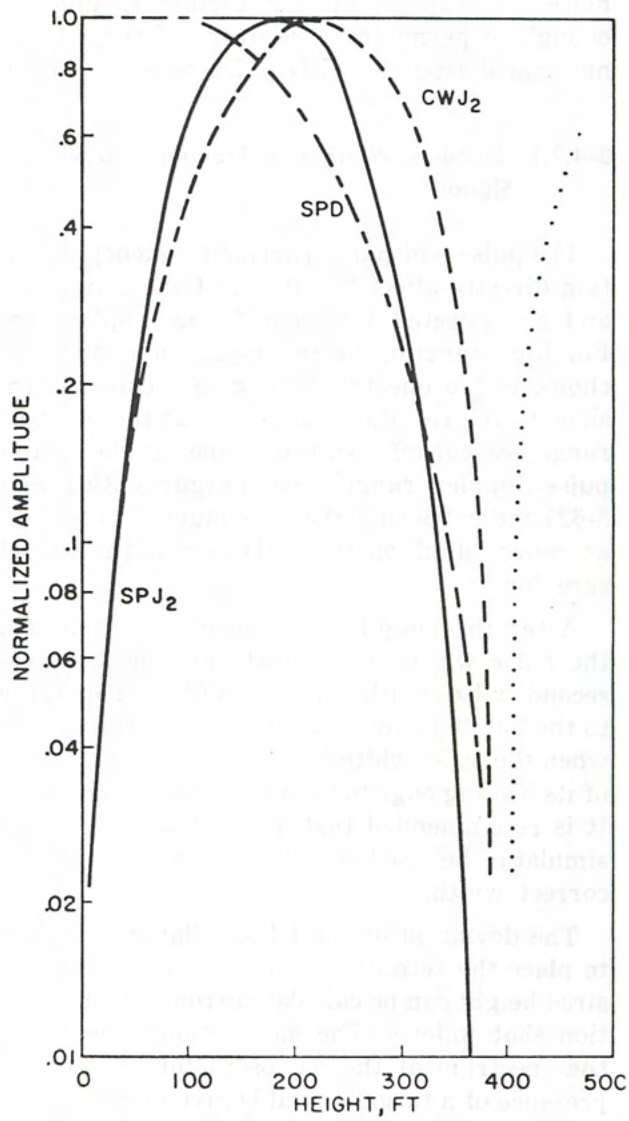

Figure 3-63 (C). Range of SPD, SPJ_2 and CWJ_2 Range Laws to CW Doppler Range Law from Simulator (390-ft Range Cutoff) (U)

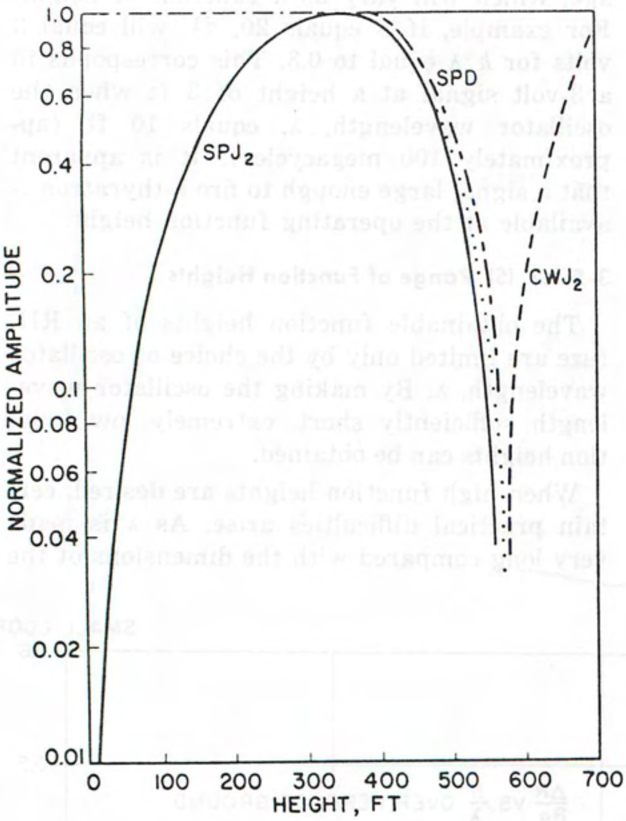

Figure 3-64 (C). Ratio of SPD, SPJ_2 and CWJ_2 Range Laws to CW Doppler Range Law from Simulator (565-ft Range Cutoff) (U)

(3) Correct ΔE for the effect of any coupling network between the grid of the oscillator and the Doppler signal output.

3-5 (S) INDUCTION FIELD FUZING (Ref. 25)

(S) A radio induction field (RIF) fuze is a variation of the convention CW Doppler fuze. It operates on a signal whose principal component is a result of the interaction of the near-zone fields from its antenna with the target (ground). These near-zone fields, commonly called the "induction fields," are given by the coefficients of $1/r^2$ and $1/r^3$ in the following equations that apply to an elementary electric dipole

$$E_\theta = \frac{j60\pi I ds}{\lambda}\left[\frac{1}{r} - \frac{\lambda^2}{4\pi^2 r^3} - j\frac{\lambda}{2\pi r^2}\right] e^{-j\beta r}\sin\theta$$

$$E_r = 60 I ds\left[\frac{1}{r^2} - j\frac{\lambda}{2\pi r^3}\right] e^{-j\beta r}\cos\theta$$

$$H_\phi = j\frac{I ds}{2\lambda}\left[\frac{1}{r} - j\frac{\lambda}{2\pi r^2}\right] e^{-j\beta r}\sin\theta$$

where

I = current in antenna element of length ds
r = distance from center of element
θ = polar angle
ϕ = azimuth angle
$B = 2\pi/\lambda$

An induction field fuze possess some unique advantages for low function height applications. The function height is relatively constant over a wide variety of conditions, and the fuze comes close to providing the desired "halo" effect, i.e., sensitivity in all directions. Because an induction field fuze is simple to construct and requires little testing, its cost is relatively low, and the simplicity of the circuit is conducive to high reliability.

3-5.1 (S) DESIGN CONSIDERATIONS

3-5.1.1 (S) Function Height

At distances greater than one wavelength, the induction field components become very small. This means that an induction field fuze is basically a low function-height fuze. Because any practical wavelength can be used, however, function heights over a considerable range are obtainable.

The equations for determining the function height of the conventional CW Doppler fuze are not applicable to the RIF fuze. Because of the discrete nature of the possible function heights, it is necessary to use the true M wave. The variation, ΔR, of the free space series radiation resistance, R_m, of a small antenna as a function of height over a perfect ground was calculated (Ref. 26) taking the total fields into consideration. The result of this calculation is given in the following equation, which is valid only for short antennas:

$$\frac{\Delta R}{R_o} = -\frac{3}{8\pi}\left\{ \sin\frac{4\pi h}{\lambda}\left[\frac{\lambda}{h}\sin^2\theta - \frac{1}{16\pi^2}\left(\frac{\lambda}{h}\right)^3(1+\cos^2\theta)\right] + \cos\frac{4\pi h}{\lambda}\left[\frac{1}{4\pi}\,\frac{\lambda^2}{h}(1+\cos^2\theta)\right]\right\}$$

where

h = height of element above a perfect reflecting plane

θ = angle betwen axis of element and the normal to the plane

The result is also plotted in Figure 3-65 for θ equal to 0 degrees. By definition of sensitivity, the signal voltage dV from a fuze oscillator of sensitivity S is

$$dV = S\,\frac{\Delta R}{R_o}$$

Therefore, if the sensitivity is known the ordinate of Figure 3-65 can be converted to voltage, which will vary as a function of height. For example, if S equals 20, dV will equal 3 volts for h/λ equal to 0.3. This corresponds to a 3-volt signal at a height of 3 ft when the oscillator wavelength, λ, equals 10 ft (approximately 100 megacycles). It is apparent that a signal large enough to fire a thyratron is available at the operating function height.

3-5.1.2 (S) Range of Function Heights

The obtainable function heights of an RIF fuze are limited only by the choice of oscillator wavelength, λ. By making the oscillator wavelength sufficiently short, extremely low function heights can be obtained.

When high function heights are desired, certain practical difficulties arise. As λ is made very long compared with the dimensions of the

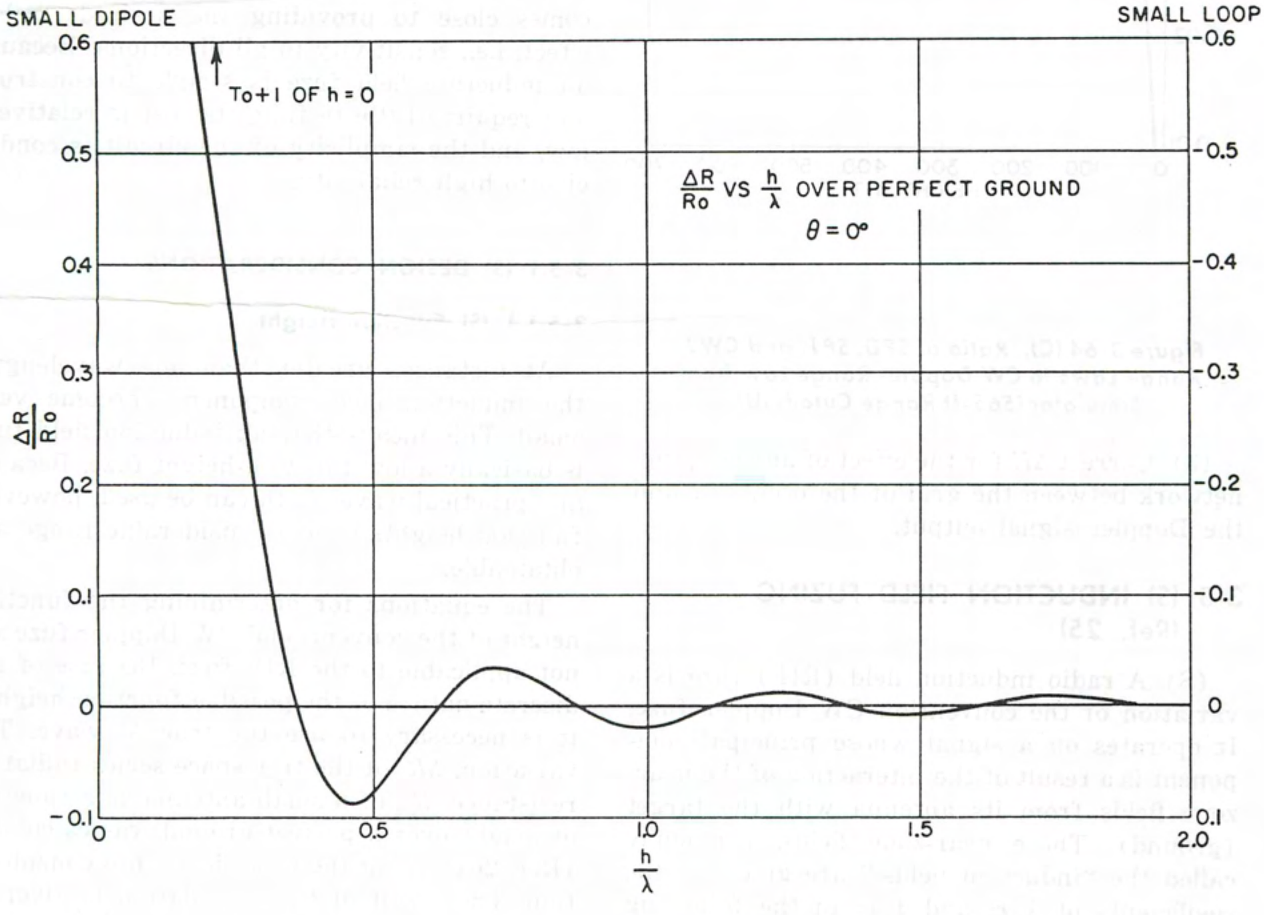

Figure 3-65 (C). $\Delta R/R_o$ vs h/λ Over Perfect Ground, When θ Equals 0 Degrees (U)

antenna (missile), the parallel radiation resistances become very large compared with the loss resistances and the internal impedance of the oscillator. Under these conditions the oscillator becomes very difficult to load and the antenna cannot be excited efficiently. This results in a decrease in the value of S and, although the value of $\Delta R/R_o$ at a given height in feet increases, a compromise must be made to obtain the maximum signal.

Wavelengths as high as 20 times the length of the antenna may be feasible by the use of special oscillators having a high internal impedance. It is possible that a λ of 16 ft (60 mc) could be used with an 81-mm mortar projectile, giving a function height of 5 ft.

3-5.1.3 (S) Variation of Height With Approach Angle

The information in Table 3-3 is compiled directly from Reference 26 and assumes that function occurs when $\Delta R/R_o$ equals 0.15. The variation in function height given in the table is typical, and would vary slightly if a different critical value of $\Delta R/R_o$ were chosen.

3-5.1.4 (S) Variation of Height With Signal Amplitude

Function height of a CW Doppler fuze is a direct function of oscillator sensitivity and ground reflection coefficient. The RIF fuze, however, experiences a rapid increase of signal amplitude as height above ground decerases. Thus, the function height of this fuze is relatively independent of sensitivity. Assuming that the signal from an RIF fuze is directly dependent on the target reflection coefficient only, the function height, h/λ, of such a fuze will vary at different approach angles as shown in Table 3-4. The factor N in the table includes relative variations in sensitivity as well as reflection coefficient. The values in the table are not unique and the range of values can be shifted depending on the firing equipment. The range of function heights over the values given for N and θ is less than 8 to 1, except where θ equals 45 degrees and N equals 0.2. Also, if the values resulting from a combination of a large θ and a high N are excluded, the range of function heights is less than 2 to 1. These values are listed below the dashed line.

TABLE 3-3 (S). Variation of Function Height With Approach Angle (U)

Approach Angle, θ (from normal)	*Function Height,* h/λ
0°	0.300
20°	0.305
30°	0.315
60°	0.410
90°	0.440

TABLE 3-4 (S). Variation in Function Height, h/λ, for Various Coefficients and Approach Angles (U)

Approach Angle, θ (from normal)	*Target Reflection Coefficient, N* 0.2	0.4	0.6	0.8	1.0
0°	0.27	0.31	0.32	0.33	0.33
20°	0.27	0.32	0.34	0.35	0.35
30°	0.26	0.33	0.35	0.37	0.38
45°	*	0.38	0.41	0.89	0.91
60°	0.35	0.42	0.91	1.40	1.42
90°	0.40	0.90	0.94	1.40	1.92

* Over a theoretically lossless flat ground with the specified N, this condition would result in zero function height. Over any natural terrain, however, an air burst would probably occur.

3-5.1.5 (S) Signal-to-Noise Considerations

Because of the large signal available from the oscillator at the function height, the effects of oscillator self-noise and microphonics are considerably reduced. The worst oscillator tubes in use have considerably less than one volt of noise output, so it may be possible to relax tube specifications for the RIF fuze, reducing the fuze cost. Similarly, the effect of power supply noise might be reduced. As the RIF fuze requires a relatively large change in antenna impedance for functioning, it should have improved immunity to interference from changes in the electrical dimensions of the antenna, such as might result from loose bomb fins.

3-5.1.6 (S) Countermeasures Resistance

The RIF fuze is more immune to countermeasures than the CW Doppler fuze because of its radically lower RF frequency. Additional countermeasures resistance is gained because it has a lower Michigan Height (see Glossary) than the CW Doppler fuze. For example, a mortar RIF fuze designed for a function height of 3 ft at an angle of 20 degrees from the vertical over average ground of *N* equalling 0.4 would have a Michigan Height of about 19 ft. A CW Doppler fuze would have a Michigan Height of about 60 ft under the same conditions.

The power needed to jam a fuze at a given range and approach angle is inversely proportional to the Michigan Height of a fuze. Therefore, it would require 10 times as much jammer power to malfunction an RIF fuze as it would a CW Doppler fuze, provided the radiated power and D-factor were the same for both fuzes. As RIF fuzes generally operate with electrically short antennas, however, it is likely that the radiated power would be les than that of the CW Doppler fuze.

3-5.2 (S) TYPICAL INDUCTION FIELD FUZE

The T796, operates on the induction field principle. It is used in the M41 bomblet, and provides a function height of about 5 ft over almost any type of terrain. A schematic diagram of the fuze is shown in Figure 3-66. The circuit is simple; consisting of only two tubes, four resistors, three capacitors, and a coaxial coil. A thermal battery provides the required operating voltage.

3-6 (S) CAPACITY FUZING (Ref. 27)

(S) Essentially, a proximity fuze measures the distance between itself and the target. When a predetermined distance is reached an action within the fuze causes the firing circuit to function, which initiates the burst. Fuzes using pulse radar or Doppler frequency for distance measuring are based on utilizing the radiation field from a radio frequency transmitter. The intensity of the receiver signal is inversely proportional to the distance to a target. Although these fuzes have a comparatively long range, they are very susceptible to environmental conditions and countermeasures; and since the frequency and phase of the received signal are not determined, advanced correlation detection methods cannot be used.

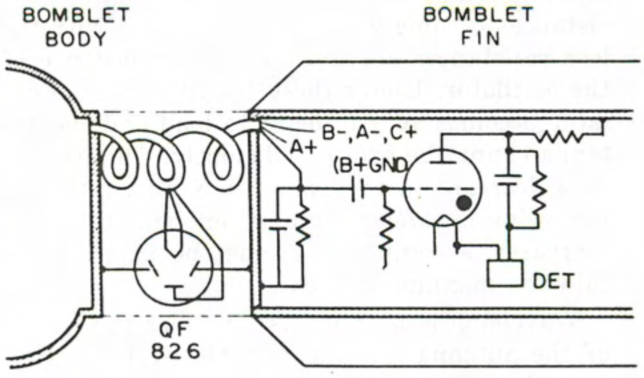

Figure 3-66 (U). Radio Induction Field Fuze

Fuzes using changes in capacitance between the target and projectile for distance measurement are based on utilizing conditions in a quasi-stationary field. In this case the received signal is inversely proportional to the second or third power of the distance. Jamming, therefore, becomes much more difficult. Furthermore, all dimensions are small compared with the wavelength; thus, the frequency and phase of the signal are well defined and phase detectors can be used.

Capacity fuzes are essentially low function height devices, and their application is similar to that of contact fuzes. They can be used when detonation is required on very near contact with a target. For example, a ground burst rather than an air burst may be desirable in certain tactical situations involving nuclear warheads. Upon impact with the ground, however, the nuclear warhead may become deformed and function improperly. To overcome this problem, a capacity fuze, through proximity action, could detonate the warhead within a few feet above the ground.

Other possible applications of capacity fuzes are standoff fuzes for antitank rounds and hand grenade fuzes.

3-6.1 (S) PRINCIPLES OF OPERATION

Various types of fuzes that use the system of measuring conditions in a quasi-stationary field have been developed. Operation of such distance measuring devices can be explained by the Monopole and Dipole principles. A detailed discussion of these principles is given in Reference 27. The cigarette fuze, currently being developed, has received the most interest. Its principle of operation is discussed in the following paragraphs. Other types of capacity fuzes are described briefly at the end of this section.

The cigarette fuze is a miniaturized capacity fuze for use with artillery ammunition. The fuze comprises a transmitter (oscillator), receiver (amplifier), battery, and safety and arming device built into a space no larger than a cigarette. This type of fuze has two advantages over conventional contact fuzes:

(1) The total length of the missile can be reduced by the use of electronic instead of physical means for achieving the most desirable burst distance or standoff.

(2) There is no problem connected with encounters on oblique surfaces.

While this small-size fuze is feasible, there are still problems in developing it as a useful military item. One major problem is the power supply, which contains several wafer dry cells that have limited shelf life and temperature characteristics.

As shown in Figure 3-67, the transmitter and receiver antennas are separated by the missile body. In the illustration, *A* is the transmitter antenna, *B* is the missile body, and *C* is the receiver antenna. An alternating voltage is produced between *A* and *B* by an oscillator. The frequency of this voltage is such that the wavelength is large compared to the missile dimensions and to any distance at which function is desired.

The oscillator, using a single tube or transistor, generates about 100 volts rms between *A* and *B*. Because the output impedance of the oscillator is low compared with any shunt capacitance, dimensional changes and raindrop effects are negligible. The operating conditions of the fuze RF section are shown in Figure 3-68.

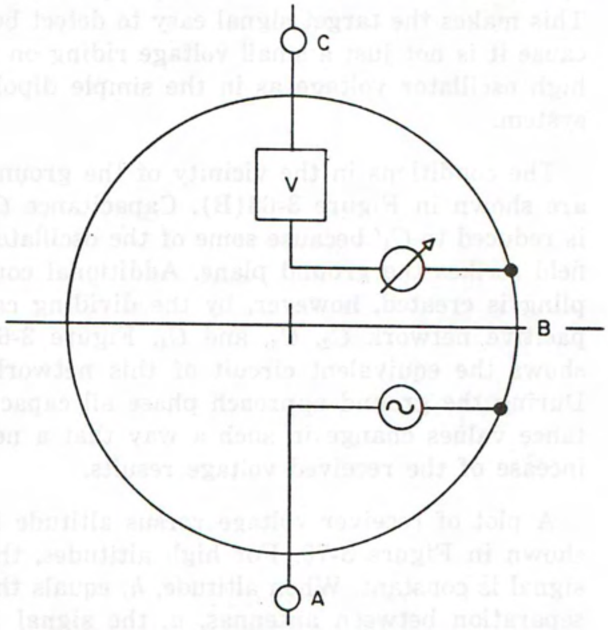

Figure 3-67 (C). Vertical Antenna Configuration for Fuze (U)

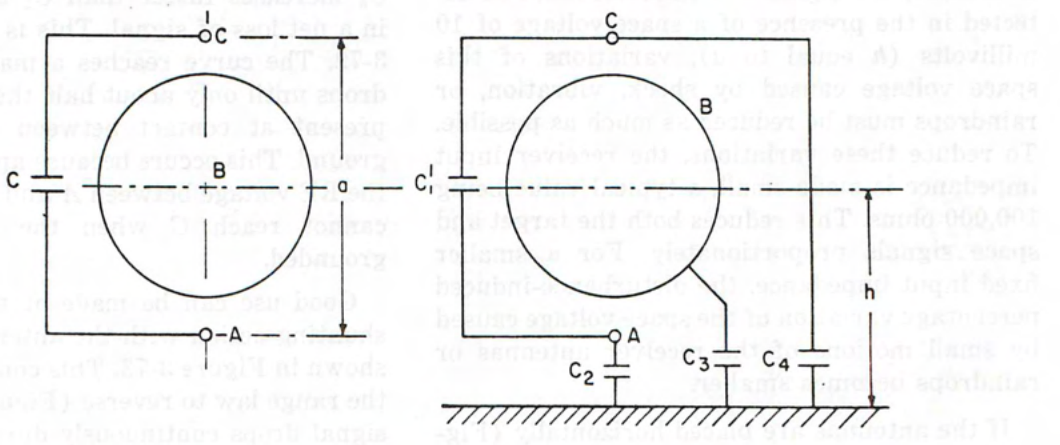

Figure 3-68 (C). Operating Conditions of Fuze. (A) Missile in Space (B) Missile Close to Ground (U)

Assume that the missile is in space (Figure 3-68(A)). The oscillator produces a field between A and B and a small part of this field creates a voltage between B and C. This coupling is indicated by capacitor C_1.

In a typical model, a spherical body with a separation of 5 in. between A and C, an oscillator output of 100 volts at 40 kc produced only 10 millivolts at the receiver input, which is a decided design advantage. The transmitter and receiver are so decoupled that, in space, only a small portion of the transmitter oscillator voltage exists across the receiver input terminals. This makes the target signal easy to detect because it is not just a small voltage riding on a high oscillator voltage as in the simple dipole system.

The conditions in the vicinity of the ground are shown in Figure 3-68(B). Capacitance C_1 is reduced to C_1' because some of the oscillator field strikes the ground plane. Additional coupling is created, however, by the dividing capacitive network C_2, C_3, and C_4. Figure 3-69 shows the equivalent circuit of this network. During the ground approach phase all capacitance values change in such a way that a net incease of the received voltage results.

A plot of receiver voltage versus altitude is shown in Figure 3-70. For high altitudes, the signal is constant. When altitude, h, equals the separation between antennas, a, the signal is 10% greater, and increases according to a third-power function of the reciprocal of the altitude. Therefore, if a signal of 1 millivolt must be detected in the presence of a space voltage of 10 millivolts (h equal to a), variations of this space voltage caused by shock, vibration, or raindrops must be reduced as much as possible. To reduce these variations, the receiver input impedance is made small, a typical value being 100,000 ohms. This reduces both the target and space signals proportionately. For a smaller fixed input impedance, the disturbance-induced percentage variation of the space voltage caused by small motions of the receiver antennas or raindrops becomes smaller.

If the antennas are placed horizontally (Figure 3-71) the range law is different. The conditions are unchanged in space, and C_1 is again

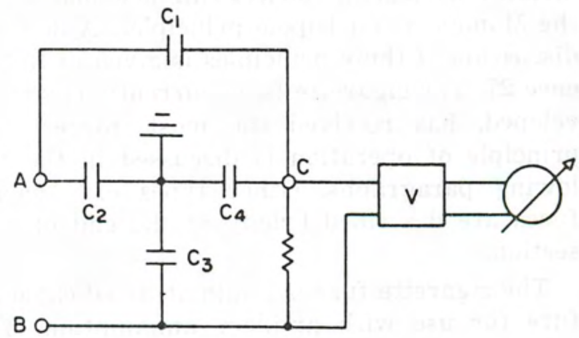

Figure 3-69 (C). Equivalent Circuit of Capacity Network Formed by Antennas and Missile Body (U)

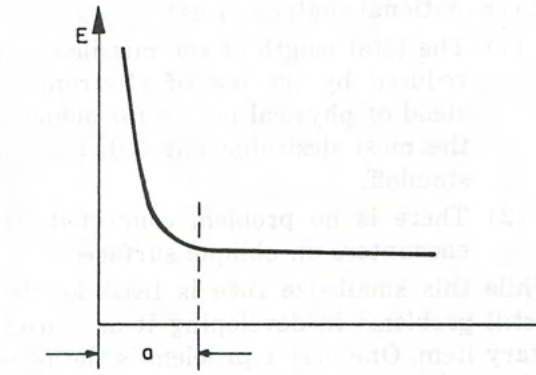

Figure 3-70 (U). Received Voltage Vs Altitude for Vertical Antenna Placement

the transfer capacity between the antennas. During an approach, the signal first increases in the same manner as with vertically mounted antennas. However, for very small altitudes, C_3 increases faster than C_2 and C_4, resulting in a net loss of signal. This is shown in Figure 3-72. The curve reaches a maximum and then drops until only about half the space voltage is present at contact between the missile and ground. This occurs because approximately half the RF voltage between A and B is shunted and cannot reach C when the missile body is grounded.

Good use can be made of the ground plane shunting action with the antenna configuration shown in Figure 3-73. This configuration causes the range law to reverse (Figure 3-74), and the signal drops continuously during an approach. Two considerations suggesting the use of this arrangement are as follows:

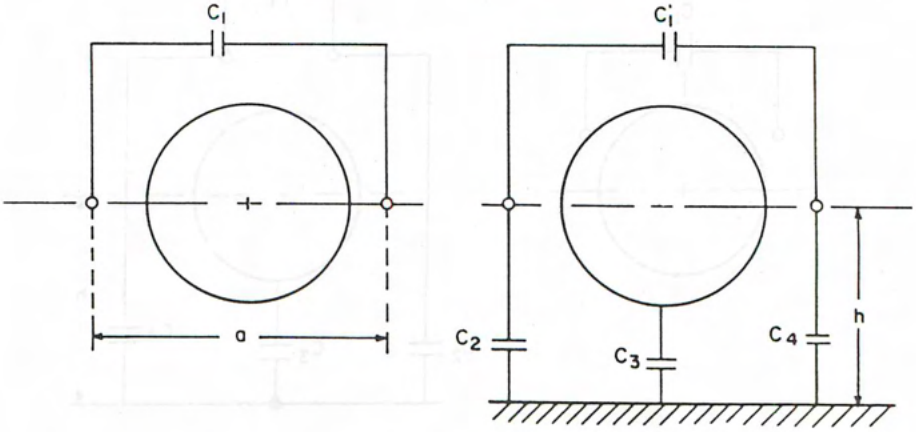

Figure 3-71 (C). Horizontal Antenna Configuration for Fuze (U)

(1) With high velocity reentry, the front end of a missile nose cone becomes hot, and therefore it is advantageous to mount the antennas at the rear end.

(2) Rear mounted antennas can be used to improve neutralization (paragraph 3-6.2.1).

3-6.2 (S) CIRCUIT DESIGN

(S) When the spacing between the antennas is larger than the desired function height, the signal increases rapidly as the desired height is approached. Because of this, a simple receiver consisting of a tuned amplifier and a linear or square-law detector can be used. For greater function heights, where the signal from the target is only a small portion of the space-signal, special methods are needed to recognize the target signal. Two methods that can be used individually or in combination are discussed in the following paragraphs.

3-6.2.1 (S) Neutralization

The use of a center-tapped oscillator tank coil is shown in Figure 3-75. A constant-voltage generator feeding the tank coil is represented by *G*. By connecting the center tap to the missile body, the voltages at either end of the coil and the missile body are 180 degrees out of phase. One end of the coil is connected to the transmitting antenna, A_1. The amplifier (receiver) is connected to the other antenna, A_2. The capacitor, C_s, represents the space-coupling and C_T is the additional capacitance produced because of proximity to ground. A neutralizing capacitor, C_n, adjusted to approximately C_s, greatly reduces the amplifier input signal when the missile is in space. Because of shock, vibration, and other environmental changes, complete neutralization cannot be obtained. However, a reduction of the space signal to 10% of its unneutralized value can be maintained indefinitely without readjustments. By this means, a function height equal to the antenna spacing can be obtained because the signal caused by the ground approach is a larger percentage at the total signal and can, therefore, be determined with greater reliability.

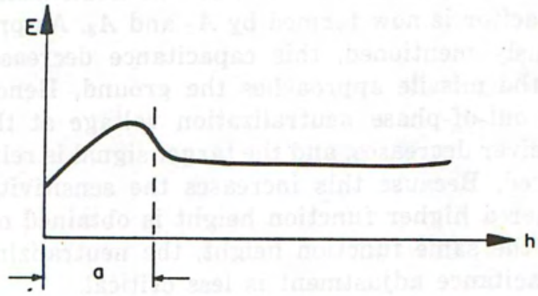

Figure 3-72 (U). Received Signal Vs Altitude for Horizontal Antenna Placement

A more refined neutralization method is

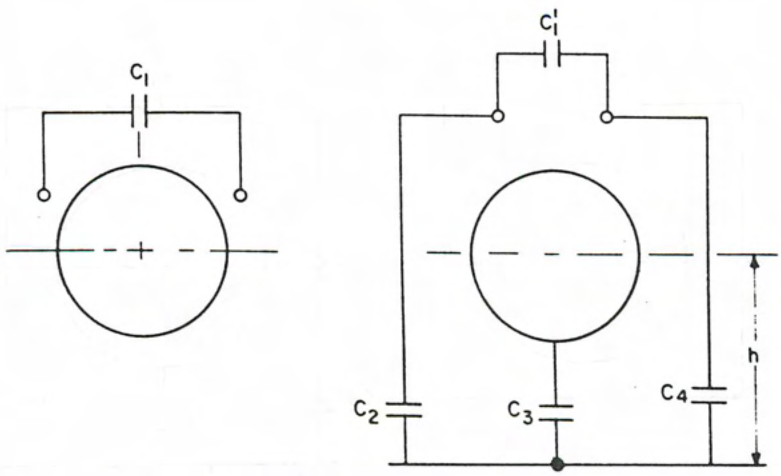

Figure 3-73 (C). Horizontal Antenna Configuration, Rear Mounted (U)

shown in Figure 3-76. A third antenna, A_3, is placed at the rear of the missile and is connected to the tank circuit as shown. The neutralizing capacitor is now formed by A_2 and A_3. As previously mentioned, this capacitance decreases as the missile approaches the ground. Hence, the out-of-phase neutralization voltage at the receiver decreases, and the target signal is reinforced. Because this increases the sensitivity, either a higher function height is obtained or, for the same function height, the neutralizing capacitance adjustment is less critical.

3-6.2.2 (S) Velocity Discrimination

The other method of increasing target-signal recognition reliability is by incorporating a filter network after the receiver detector. The filter responds chiefly to the envelope components produced during the approach to the target. The received signal is constant while the missile is in space. As the missile approaches the ground, the signal increases according to the range law and the approach velocity. The voltage build-up may occur very rapidly. During the time it takes to go 2 ft at a velocity of 2000 ft per second, the target signal increases from zero to triggering value within one millisecond. Therefore, if the filter network has its maximum peak at 1000 cycles per second, it will discriminate in favor of the target signal. However, modulation frequencies in the pass-band of the filter may be produced by shock and vibration, decreasing the signal-to-noise ratio. Using neutralization to reduce the

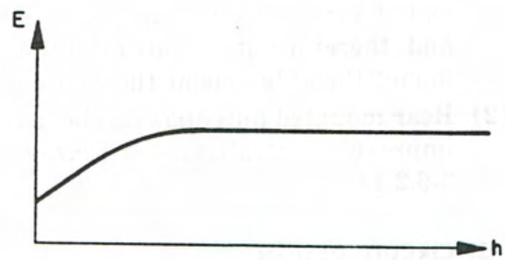

Figure 3-74 (U). Received Voltage Vs Altitude for Horizontal Antenna Configuration, Rear Mounted

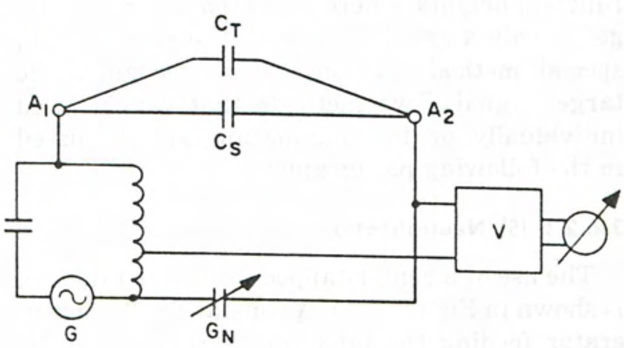

Figure 3-75 (C). Typical Neutralization Circuit Using Center Tapped Tank Coil and Neutralizing Capacitor (U)

space signal and its microphonic envelope about 20 db gives an improvement in this ratio. Function heights considerably higher than the antenna spacing could be obtained by this method.

3-6.2.3 (S) Bandwidth and Detection

To make the fuze resistant to countermeasures, the bandwidth of the amplifier should be greatly restricted. Still, it must be wide enough to accommodate the amplitude envelope during the approach. For example, if the signal buildup occurs in one millisecond, a minimum bandwidth of 2,000 cycles per second is needed. If predetection selectivity is desired, the receiver must be tuned accurately to the oscillator frequency. Thus, the receiver must be free from drift or must drift with the oscillator so that the fuze can be used without retuning after long storage periods. Furthermore, the frequency-determining components must be sufficiently rugged to eliminate frequency modulation due to vibration and shock.

The use of a coherent detector (Figure 3-77) obviates these stringent requirements. In the illustration, A_1 and A_2 are the transmitting and receiving antennas. The oscillator is represented by two batteries and a switch, S_1. With this switch the voltage at A_1 can be changed periodically between positive and negative values. The receiving antenna, A_2, is connected to a wide-band amplifier, whose output is switched by S_2, in synchronism with S_1, alternately to capacitors C and C'. The indicating instrument is a d-c voltmeter connected between the capacitors. The time constant and the bandwidth are determined by the mechanical inertia of the meter movement and by the values of C and R.

The synchronous operation of S_1 and S_2 charges C positively and C' negatively, and the meter indicates the voltage difference between C and C'. Only voltage at the transmitter frequency can produce a steady d-c output. Other signals only cause fluctuations of the meter around its zero point. Maximum output is obtained if the two signals are in phase; there is no output for phase quadrature conditions.

In actual design, S_1 is the oscillator and S_2 the electronic gate that is controlled by the oscillator. The selectivity is determined by the time constant of the post detection network.

An important advantage of using a coherent detector is that the signal-to-noise ratio is the same after detection for a predetection signal with a S/N ratio of less than one (Ref. 28). In a conventional detector the ratio is reduced to $(S/N)^2$.

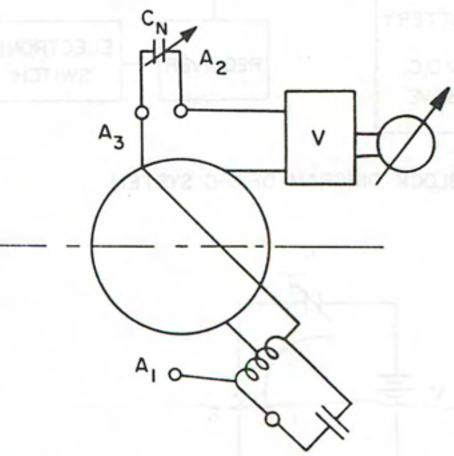

Figure 3-76 (C). Refined Neutralization Method Using Additional Antenna to Form Neutralizing Capacitor (U)

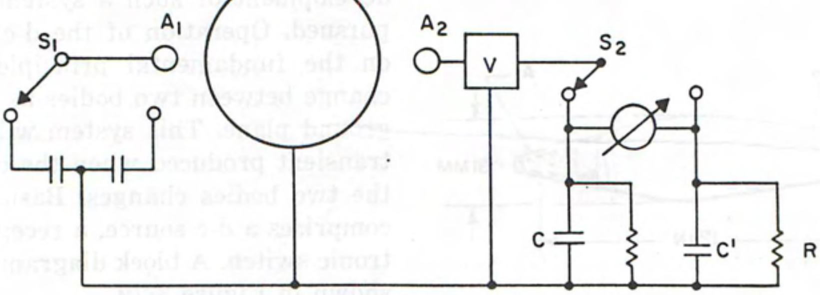

Figure 3-77 (C). Simplified Coherent Detector (U)

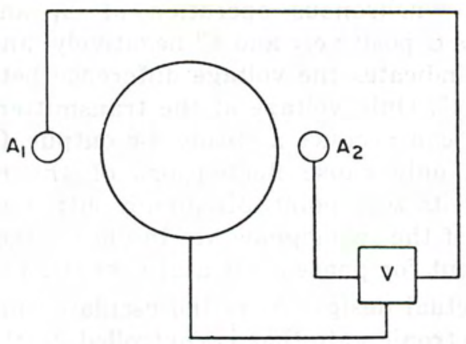

Figure 3-78 (U). Basic "Sing-around" System

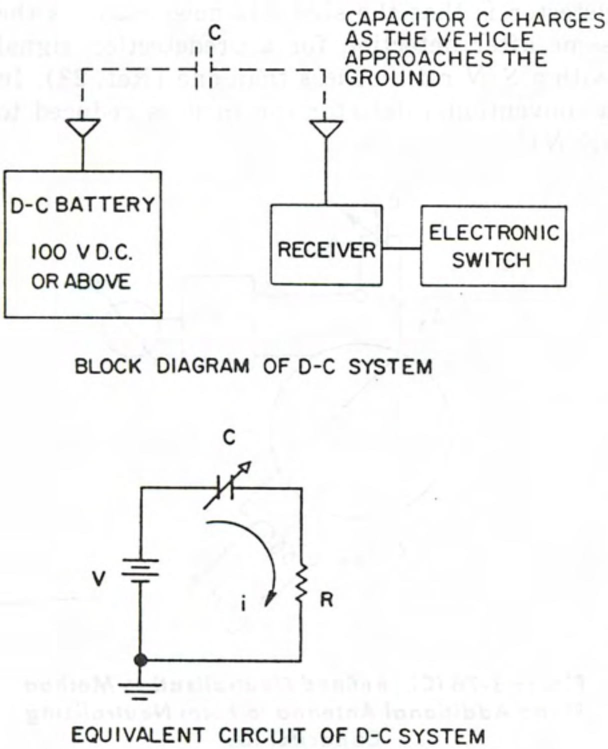

Figure 3-79 (C). Block Diagram of D-c Capacity Fuze System (U)

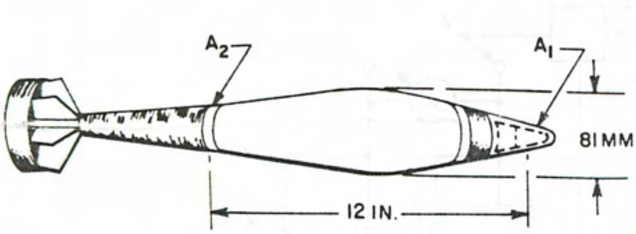

Figure 3-80 (C). An 81-mm Mortar Projectile With Capacity Fuzing (U)

Using a coherent detector improves the fuze countermeasures resistance. By adjusting the neutralizing capacitor for zero signal at a predetermined altitude instead of in space, a phase reversal of the total input signal occurs when the missile passes this altitude. As this change takes place, the d-c output voltage goes from a positive to a negative value. This can be recognized by a differentiating network between the detector and firing circuit to provide additional counter-countermeasure protection.

3-6.3 (S) SING-AROUND SYSTEM

A variation of the system previously discussed is shown in Figure 3-78. It is called the "sing-around" system, and requires no oscillator. The operating signal is produced by a feedback path between the amplifier output and input terminals. This path is formed by the field between the missile and the target, and causes the amplifier to oscillate. This type of fuze is cheap and still maintains the worthwhile counter-countermeasure features of the coherent detector. It is an "on-off" device and the signal build-up during approach cannot be observed.

The amplifier gain must be adjusted so that the field in space is not enough to cause oscillations. The start of oscillations depends not only on the altitude but also on the presence of transients or noise pulses during the critical period in which the impedance of the network swings from a positive to a negative resistance. This means that the fuze is useful only when precise function heights are not mandatory.

3-6.4 (S) D-C CAPACITY FUZE (Ref. 29)

A capacity fuzing system using a high-voltage, direct-current source has been studied, but development of such a system has never been pursued. Operation of the d-c system depends on the fundamental principle of capacitance change between two bodies as they approach a ground plane. This system will operate on the transient produced when the capacity between the two bodies changes. Basically, the system comprises a d-c source, a receiver, and an electronic switch. A block diagram of the system is shown in Figure 3-79.

This system does not require an oscillator or neutralizing voltage. However, a low-current, high-voltage d-c source is needed. The system may be more resistant to countermeasures and physically smaller than the RF system.

When applied to fuzing a missile, the system has certain disadvantages. Maintaining the d-c potential in rain is difficult. Also, the signal current depends on the approach velocity, making constant-altitude fuzing difficult.

3-6.5 (S) SPECIFIC FUZING APPLICATIONS

3-6.5.1 (S) Mortar Fuzing

Figure 3-80 shows an experimental 81-mm mortar projectile equipped with a cigarette-type capacity fuze. The receiver antenna is formed by a flush-mounted metal ring located well in front of the tail fins. The transmitter antenna is an insulated nose cone. The spacing between the antennas is 12 in. The oscillator and amplifier are completely transistorized and are operated by a 1.5 volt thermal battery. The oscillator operates at 25 kc and has an output of 100 volts rms. The amplifier has a gain of 80 db and an input impedance of 150,000 ohms. In space, 4 millivolts are developed between the receiver antenna and the missile body. Neutralization and velocity discrimination are used. A number of these mortar rounds were test fired to determine their resistance to shock and vibration. Of 16 rounds known to be true tests, all fuzes functioned properly. A complete description of this fuze is given in Reference 30.

3-6.5.2 (S) XM28 Near Surface Burst Fuze System

The XM28 near surface burst fuzing system is used for artillery projectiles equipped with nuclear warheads. The system is shown in Figure 3-81. The transmitter and receiver antennas are located on the missile extremities. The oscillator operates between 20 and 100 kc. The input impedance is approximately 150,000 ohms. Certain stages of the amplifier are designed to attenuate frequencies below 20 kc to reduce the effects of microphonics. The fuze is fully described in Reference 31.

3-7 (S) PULSED RADAR

(U) Pulsed radar fuzes, operating in the VHF/UHF portion of the RF spectrum, have been considered for a number of applications. Both the superheterodyne type and the tuned radio frequency (TRF) type have been investigated.

3-7.1 (C) SUPERHETERODYNE TYPE (Ref. 32)

Superheterodyne pulsed radar fuzes operating in the UHF region have been designed for high altitude ground approach applications. These fuzes are essentially miniaturized conventional pulsed radar systems. They have been considered for use in applications such as parachute delivery of cargo, bomb fuzing, and ejection of personnel from disabled high-speed aircraft. No VHF/UHF superheterodyne pulse

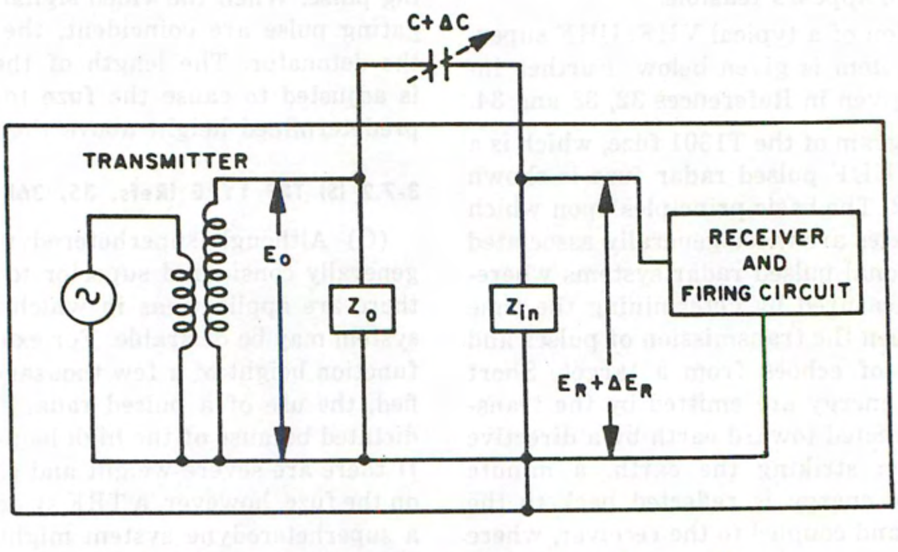

Figure 3-81 (C). Near Surface Burst Fuze System (U)

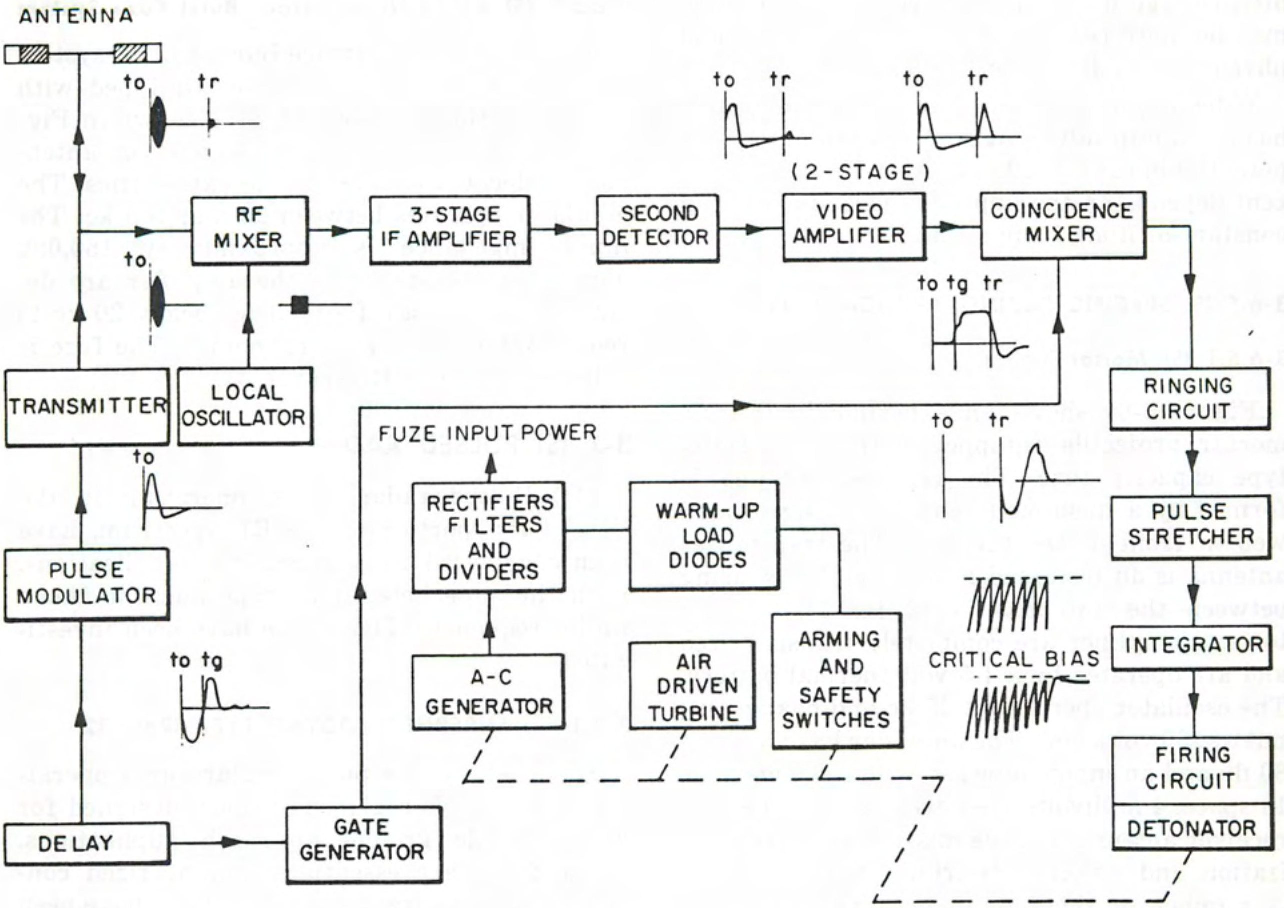

Figure 3-82 (C). Block Diagram of Bomb Fuze (U)

radar systems are in use (1961); however, a great deal of development work has been done and the system appears feasible.

The operation of a typical VHF/UHF superheterodyne system is given below. Further information is given in References 32, 33 and 34.

A block diagram of the T1301 fuze, which is a typical VHF/UHF pulsed radar fuze is shown in Figure 3-82. The basic principles upon which the fuze operates are those generally associated with conventional pulsed radar systems wherein range is measured by determining the time interval between the transmission of pulses and the reception of echoes from a target. Short pulses of RF energy are emitted by the transmitter and directed toward earth by a directive antenna. Upon striking the earth, a minute portion of the energy is reflected back to the fuze antenna and coupled to the receiver, where the signal is converted to an IF signal, amplified, and converted to a video signal. The video signal is then matched with a timed video gating pulse. When the video signal and the video gating pulse are coincident, the fuze actuates the detonator. The length of the gating pulse is adjusted to cause the fuze to function at a predetermined height above the terrain.

3-7.2 (S) TRF TYPE (Refs. 35, 36)

(C) Although superheterodyne systems are generally considered superior to TRF systems, there are applications in which a TRF fuzing system may be desirable. For example, if a fuze function height of a few thousand feet is specified, the use of a pulsed radar fuze is usually dictated because of the high loop-gain required. If there are severe weight and size restrictions on the fuze, however, a TRF system rather than a superheterodyne system might be used. The TRF system results in considerable savings in weight and complexity because a local oscillator, mixer, and AFC circuit are not required.

3-7.2.1 (S) Basic Operation

A block diagram of a typical TRF pulse radar fuze is shown in Figure 3-83. This particular arrangement was designed for air burst at about 2,500 ft above the ground. The transmitter is a light-house type triode oscillator. Typical operating parameters of the system are peak pulse power, 1 kw; repetition rate 20,000 ppps; pulse length, 0.3μ sec. Modulation is accomplished by an hard-tube modulator, with prf jitter included for counter-countermeasure purposes. The receiver is a TRF amplifier centered at the transmitter frequency. Air burst is accomplished by gating a coincidence tube at the desired altitude. The coincidence tube drives a one-tube jittered, high prf, integration-type decision circuit, which delivers a firing signal consistent with a programmed false alarm rate and probability of detection.

3-7.2.2 (U) Loop Sensitivity and Signal Return

For a ground target that reacts as partially diffuse and partially specular, the power returned due to the diffuse return is

$$P_r = \frac{\alpha P_t \rho \lambda^2 c}{32\pi^2 R^3} G_t G_r$$

where

P_r = peak power returned
P_t = peak power transmitted
R = height above ground
τ = pulse width
c = velocity of light
ρ = reflection coefficient of target
λ = wavelength
G_t = gain of transmitting antenna
G_r = gain of receiving antenna
α = fraction of total reflected power that is diffusely reradiated

and all dimensions being consistent.

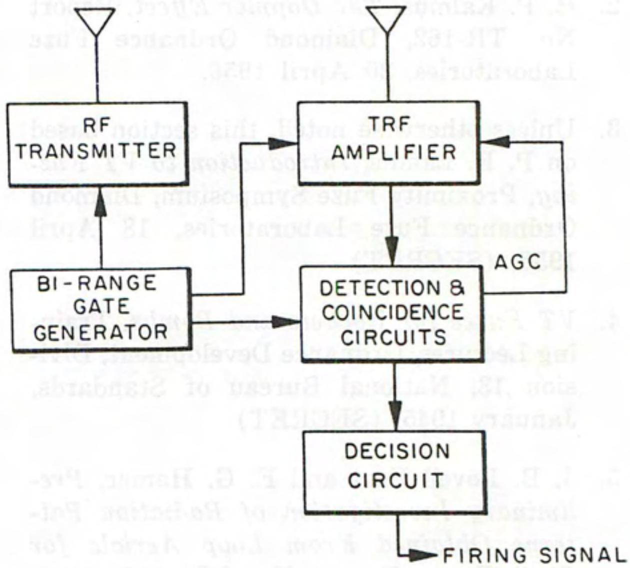

Figure 3-83 (C). Block Diagram of a Typical TRF Pulsed Radar Fuze (U)

The power returned due to the specular return is

$$P_r = \frac{\beta P_t \rho \lambda^2 G_t G_r}{64\pi^2 R^2}$$

where

β = fraction of total reflected power that is specular

For almost all practical cases, α is much greater than β. The equation for the diffuse return assumes a pulse width limited case; i.e., only that energy returned within the pulse width time is considered. This limitation will determine the illuminated area.

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