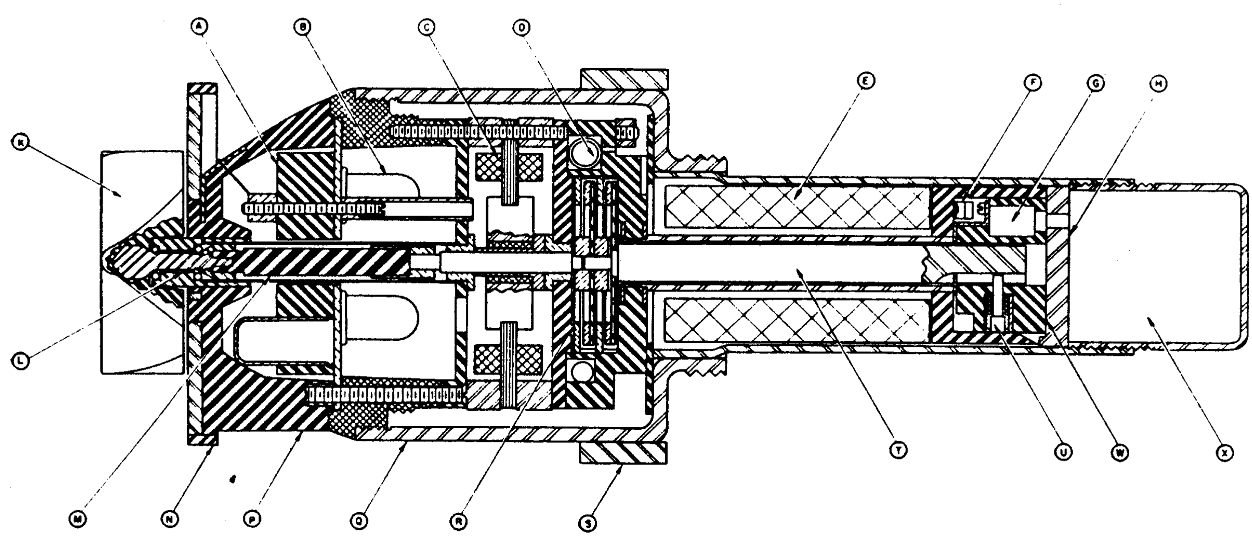
Radio Proximity Fuzes

Residents of the United States born much after 1930 can have little appreciation for what it was like to mobilize for total war. In World War II, everyone and every facet of daily life was affected. All citizens had to learn to live with food and fuel rationing, and no new cars or other consumer products made from steel could be purchased. There were blackouts, air raid drills, scrap drives, school children buying War Bonds (a 10 cent stamp at a time), and, of course, able-bodied men and women taken either into military service or placed in critical jobs in industry and elsewhere. Institutions such as the National Bureau of Standards were likewise totally involved in the war effort. The Bureau found itself with a number of very important technical assignments and, for a change, the resources to carry them out In October 1939, after Albert Einstein and Leo Szilard urged the President to launch a major research program on the possibility of producing nuclear fission and utilizing it in the likely war effort ahead, NBS Director Lyman Briggs was placed in charge of a new Advisory Committee on Uranium to look into this proposal. By 1941 some 90 % of the NBS staff was doing war work.

The Bureau worked on a great diversity of war projects ranging from high technology to evaluating materials for blackout curtains and blackout masks. A major effort carried out with the Navy and the Radiation Laboratory at MIT was the development and fielding of the Bat, the first combat success with a fully automatic guided missile (really a bomb with wings and a tail looking rather like a modern Unmanned Aerial Vehicle or UAV). The story of the Bat has significant technology in common with the proximity fuze program; namely, the use of electromagnetic radiation sources on flying ordnance and the interpretation and use of the reflected waves to carry out the mission.



A Oscillator block
B Amplifier
C Generator
D Rectifier
E Filter condenser
F Contacts to detonator
G Detonator
H Tetryl plate
K Windmill
L Vane bearing assembly
M Drive shaft
N Antenna (in later models, antenna extended forward to enclose vane)
P Insulating support for antenna
Q Fuze housing ("potato masher")
R Speed reducing gears
S Lugs for wrench
T Low-speed drive shaft for arming mechanism
U Locking pin for detonator rotor
W Detonator rotor (arming consists of rotation of this piece into proper position)
X Booster cup

Fig. 1. Sectionalized drawing of T-50 type bomb fuze. The same general arrangements of parts was used for all ring-type bomb fuzes (from [1]).

This is the atmosphere in which the Bureau undertook the work on proximity fuzes, work that had a profound impact on NBS for many years thereafter as well as providing the military with breakthrough applications of technology. Bureau staff at the end of World War II prepared the book titled *Radio Proximity Fuzes for Fin-Stabilized Missiles* [1]. It summarized all the work done from about 1940 through 1945. It is a monograph; that is, a stand-alone comprehensive presentation of the entire program. Allen Astin, then assistant chief of the Ordnance Development Division of the Bureau, edited the work. (Harry Diamond was chief; W. S. Hinman, Jr. was chief engineer.) The work was published under the auspices of the National Defense Research Committee (NDRC) and the Office of Scientific Research and Development (OSRD) and classified at the Secret level. It was declassified in 1960. The volume under discussion is one of three covering the work done by Division 4 of NDRC titled *Ordnance Accessories.* It should be pointed out that parts of the program were ably carried out by contracts with companies and universities, a mode of operation learned well in the war and likely very comfortable for the Bureau staff, given their history of collaborations with the private sector. It has been asserted that the radio proximity fuze effort consumed "about 25 % of the electronics manufacturing capacity and 75 % of the plastics molding capability" of the Nation during the war [2]. Authorship of the various chapters is by Bureau staffers who spent the war in the Ordnance Development Division and its subsequent subdivisions. Authors included such well-known names as Robert D. Huntoon, Chester Page, and Jacob Rabinow; Rabinow's wife, Gladys, is listed as a contributor to one chapter.

The problem assigned to the Bureau was to conceive and realize a fuze system for non-rotating, fin-stabilized munitions (ordnance) such that detonation could be obtained at a specified distance from the target. Such performance is desirable for two reasons: first it is often difficult to produce a direct hit, and it is acceptable to achieve detonation close to the target. A good example is trying to hit an airplane or a rocket. A direct hit was well beyond the technology available in the 1940s and remains a challenge today for the anti-ballistic missile program. Secondly, more damage can often be obtained by detonation at some distance removed from the target. Air bursts over ground targets are effective over wider areas than explosions on the surface, where much of the energy goes to producing a crater. Air bursts are particularly effective against dug-in ground troops and against stored materiel. The ordnance addressed at NBS were rockets, bombs, and mortar shells. Both the Army and the Navy provided performance specifications for such fuzes and the program came to the Bureau for execution. The specifications varied for the several applications, and the program was directed to make as much as possible common to all.

The first job was to select the basic concept. Although some thought was given to acoustic, photoelectric, and passive radio systems, an active radio scheme was adopted early on. As a result of the Bureau's great successes with radio earlier and with radiosondes more recently, the choice of the radio scheme led directly to a major technical strength of NBS. Management could and did assemble a powerful team, largely from within but augmented by cooperation with the Navy and, at times, with our Allies in England. Radio waves could be employed by using time-of-flight measurements on the path from and reflected back to the ordnance in flight or by using the Doppler shift of the reflected radiation. The reflected waves are shifted to a somewhat higher frequency as the missile flies toward the target. Using the transmitting antenna as the receiving antenna, this reflected wave sets up a beat frequency in the oscillator circuit. Transmitting at 75 MHz to 110 MHz produced a beat frequency of a few hundred hertz, the exact value depending on the relative velocity of missile and target and the transmitting frequency. These details were considerably different for rockets, bombs, and mortar shells. Nonetheless the concept worked in all cases.

It turns out that this situation is equivalent to a time-varying impedance at the antenna terminals. The amplitude of this signal increases with the strength of the reflection; i.e., with decreasing distance to the target. By using the impedance, it is shown that the sensitivity to reflection is independent of power level over a wide range, thereby enabling application to many different systems. A variety of interferences are treated in detail in Chapter 2 of the book, including different antenna designs, ground effects, target geometry, and the like.

The differential signal from the antenna circuit was fed to an amplifier and, depending on the design, through a rectifying diode and thence to the grid of a thyratron. When this signal reached a set magnitude, the thyratron discharged into a detonator circuit and the fuze mission was complete. Details of the control circuit are in Chapter 3. The concept was first demonstrated in February 1941. What lay ahead was a long, painstaking series of engineering projects to put together a series of fuzes that not only detonated the munitions successfully, but also met the armed services requirements for safety, reliability, ease of manufacture, and shelf life. In addition, for most of the fuzes there was an additional requirement that they had to fit into existing fuze wells on existing ordnance. These practical considerations were non-trivial and required considerable ingenuity. Few of the available electronic components were suitable. Industry was pressed into service to design and prove out new triodes, diodes, pentodes, thyratrons, and a variety of power supplies—an assignment carried out in a timely fashion. The mechanical systems such as safety designs and arming schemes, as well as alternate detonation systems for situations where the proximity fuze did not work for whatever reason, were described in Chapter 4.

Chapter 3 also addresses the question of providing electrical power to the circuits, both by batteries and by mechanical generators. The batteries were either ordinary dry cells or "reserve" types that were activated by the forces of launch wherein an ampoule containing the electrolyte was broken and the electrodes and electrolyte brought together. The "reserve" concept was demonstrated but not fielded; the idea would come to be used often years later when the technique had been perfected. Dry batteries were used in the early fuzes but suffered shelf life problems. Much effort was directed to the notion of a wind-driven turbine connected to a generator. This had safety advantages—no possibility of electric currents prior to flight—was fairly simple in design and manufacture, and proved to be the method of choice.

The remainder of the volume contains a catalog of fuze types, details of laboratory testing, details of field testing, a resume of actual performance at the latter stages of the war, and a formal analysis thereof. It is interesting to note the thoroughness of field testing as exemplified by the number of units tested: for bombs—15,000 dropped at Aberdeen Proving Ground in Maryland; for rockets fired from the ground—nearly 24,000 fired at Ft. Fisher in North Carolina and Blossom Point, Maryland (plus a few at Aberdeen); and some 3000 mortar shells fired at Blossom Point and the field station of the University of Iowa at Clinton, Iowa. Chapter 9 contains an analysis of performance. At the end of this chapter is a summary of conclusions by the armed services concerning results in combat.

Curiously, the driving force behind the work, Harry Diamond, seems not to have written any of the report. Nonetheless, he was the dominant figure throughout the war and established an atmosphere that made the great success possible. Diamond was a dynamo himself but evidently a very remarkable man to work for. He believed in delegation and a minimum of formality. Here is a quote from an appreciation written after his death [2]:

> "It was a madhouse. I didn't have a vacation during the entire war. Nobody knew who was in charge and nobody cared . . . they describe those days with tangible affection, even as 'great fun'. . . . If someone needed help, they got help. If someone needed equipment, they got it. No questions asked. . . . "

The armed services' comments are of special interest since they ensured the future post-war work at the NBS laboratories. Fuzes for rockets and bombs went into mass production and were used extensively toward the end of the war. Mortar shell fuzes did not go into full production. The conclusions from the services began with the following statement:

> "The general attitude of the using arms to the bomb and rocket VT [proximity] fuzes at the end of World War II was most favorable. Originally there was much doubt as to their possible value as a lethal weapon. The general attitude was that the fuzes had very limited use, that they were unsafe, and that a high percentage of them malfunctioned. Combat experience in the various theaters changed this view, and with the close of World War II the using arms were very enthusiastic over the fuzes."

Vannevar Bush is said to have considered the radio proximity fuze the preeminent scientific and technical advance of the war. Considering the Manhattan Project and radar, this is a startling statement. Another historian ranked the fuze as follows "Considering the magnitude and complexity of the effort [it ranks] among the three or four most extraordinary scientific achievements of the war." General George Patton said, after the fuze had performed notably at the Battle of the Bulge, "The new shell with the funny fuze is devastating . . . I think that when all armies get this shell we will have to devise some new method of warfare." [2].

Allen Astin, in his closing comment, stated that, as of 1946, the Army Ordnance Department had already formulated a further program and that the Ordnance Development Division at NBS was working for the Army on new fuze challenges.

It turned out that the NBS effort on fuzes continued in a very strong manner in the post war years and that military work came to dominate the work of the Bureau. The basic concept of using the Doppler shift in frequency of the reflected radiation and beating it against the transmitter's oscillator frequency continued to be used in these fuzes after the war. Ultimately the fuze systems became "first class radars" [3]. Technical work focused, inter alia, on security from jamming and thus involved various ways of disguising the signal. The reserve battery power supply was perfected and thermally-activated batteries became the method of choice. A quick perusal of the table of contents of an Army ordnance manual from 1963 shows major emphasis on continuous wave and pulsed Doppler fuzes. Eventually, of course, miniaturization through solid state and integrated circuits became possible. Technical director Horton marveled that the early fuzes using electron tubes were able to survive the stresses of launch.

The Kelly Committee, an ad hoc group, was formed by the NBS Visiting Committee and the National Academy of Sciences at the request of Commerce Secretary Sinclair Weeks after the uproar created by the AD-X2 battery additive controversy. The Committee report of 1953 recommended that the Bureau get back to its congressional charter and separate the bulk of its military work. Cochrane [4] says that 2000 staff were transferred to other agencies, some 1600 of these in three divisions that worked on fuzes. Those three divisions had earlier been placed in the Harry Diamond Ordnance Laboratory within NBS, the unit named in honor of the memory of Harry Diamond, who died at the early age of 48 years in 1948. The Army added the word "Fuze" (and dropped the "Harry") to the title on receipt of the unit—thus, the Diamond Ordnance Fuze Laboratory, or DOFL. The remainder of the affected staff worked on guided missiles at a location in California and were shifted to the Navy. The DOFL remained at the Connecticut and Van Ness site until a new laboratory site could be completed in White Oak/ Adelphi, Maryland. The move was carried out in 1973. This is just one of many examples of significant technical entities created out of the NBS over the years.

The DOFL had a distinguished history in the Army. It continued to work on fuzes although eventually turning over most of the work to various product development and engineering centers, such as Picatinny Arsenal and the Redstone Arsenal. The laboratory at Adelphi developed major research programs in high-power microwaves, electronics, nuclear simulation, radar, sensors, and signal processing—a broad, multi-program laboratory. In 1992 it became one of the major components of the new Army Research Laboratory and the Adelphi site served as the new entity's headquarters. The central building in the complex carries prominently on its façade the name "Harry Diamond Building." Inside are portraits of Diamond and Hinman and displays of the early fuze artifacts and documents. In a curious coincidence John Lyons, ninth director of NBS/ NIST, became, in 1993, the first director of the new Army Research Laboratory and made his offices in the Harry Diamond Building. In a sense he felt he had simply moved to one of the Bureau's more significant descendants. He served ARL as its director through 1998, when he retired.

Allen Astin went on to become the fifth director of NBS and served the second longest tour of any director− from 1952 to1969. Diamond died shortly after the war; his close associate, W.S. Hinman, Jr., succeeded Diamond as head of the program and became the first technical director of the DOFL after it moved to the Army. After staying with the DOFL for a few years, Hinman moved on to become the Deputy Assistant Secretary of the Army (Research & Development). Robert Huntoon served as a senior manager at NBS heading atomic and radiation physics. He later became Associate Director of NBS for Physics and, still later, Deputy Director as well. J. Rabinow had a distinguished career as an inventor and innovator, left NBS to form a company which he later sold to Control Data. He returned to NBS and served in various senior capacities and was at work at least part-time until his death in 1999 at the age of 89. Chester Page went on to head the Electricity Division for many years and made many contributions, not least of which were his efforts in developing the concepts that became the international system of units of measurement (SI).

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