The Radio VT Fuze

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One of the best kept secrets of WW II was the VT fuze also known as the proximity fuze. This device was used in various forms on rockets, antiaircraft shells and antipersonnel bombs - both those dropped from airplanes and those fired from howitzers. A typical VT fuzed artillery shell contains a miniature CW radar system which senses that the bomb is near enough to its target (about 30 feet) to be effective and then triggers the detonation. See Fig. 1. British scientists conceived the idea in 1940 and passed it on to the Americans who developed the technology and brought these weapons to fruition in time to play an important role in WW II in both the European and Pacific theaters.

Fortunately for our soldiers and sailors, the Germans didn't have VT fuzes. One author[4] says the reason for this is that the German engineers were too smart - they felt it would be impossible to make a radio tube that would withstand the extremely high acceleration (about 20,000G) experienced by an antiaircraft shell at the moment of firing or the centrifugal force (800-3000G) due to axial rotation imparted by the rifling of the cannon barrel.

Ruggedized Tubes Developed

The components requiring the most intensive research were the tiny vacuum tubes. Subminiature tubes were already in existence having been developed for use in personal hearing aids. After redesign and extensive testing, a set of tubes was developed to be able to meet the demanding needs of the VT fuze. These included triodes, pentodes and thyratrons. Fig. 2 shows three subminiature tubes (two triodes and a pentode) alongside a 1T4 7-pin miniature tube for size comparison. The pentode, weighing about half the weight of a U.S. nickel, would weigh 110 pounds at 20,000G acceleration.

Each component part used in these tubes was designed using stress and strain analysis like that used in designing bridges and skyscrapers. The tubes were then subjected to rigorous tests, first by computation and then by actual mechanical means such as in a centrifuge or by firing them out of a cannon after being mounted in dummy shells. These shells would then be dug out of the ground, the tubes recovered and then analyzed for signs of weakness or failure. Most of the tubes were manufactured by Sylvania Electric Co. By war's end, production reached 500,000 per day. Total production was about 130 million tubes.

Basic VT Fuze Circuit

A representative circuit is shown in Fig. 3. The first tube, V1, is a simple regenerative detector similar to those used in early amateur radio receivers. As is well known, these regenerative detectors radiate a radio signal when they are adjusted so as to oscillate. The VT fuze is provided with a nose cone made of hard plastic which encloses an antenna element in the shape of a small metal cone. This, together with the metal body of the shell constitutes or forms an unsymmetrical dipole antenna. This antenna serves two functions. It radiates the radio wave that intercepts the target and it also receives the much weaker reflected wave and applies it to the detector. Thus V1 acts as both the transmitter and the receiver. The re-

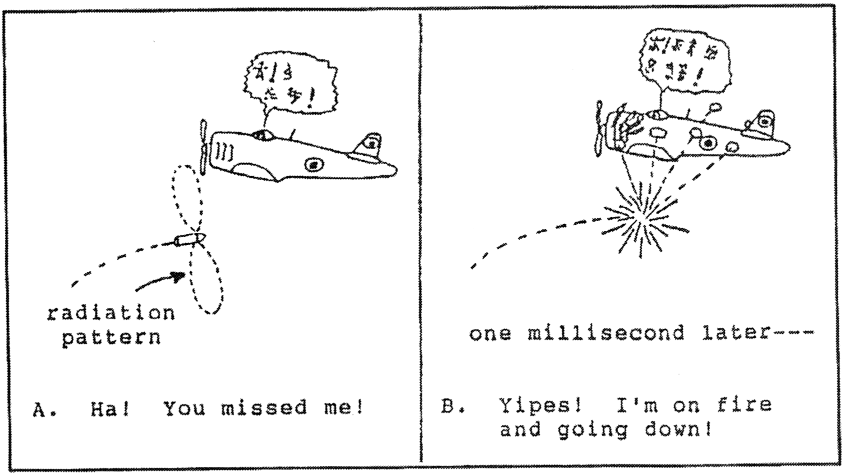

Figure 1. With a VT fuze, a near miss is a hit.

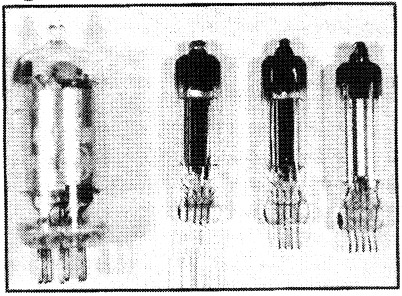

Figure 2. Subminiature tubes compared with 7-pin miniature tube.

ceived wave has a changing phase relation with respect to the emitted wave depending on the velocity of the shell relative to the target. These two signals produce an audio beat frequency in the plate circuit of V1. This is a result of the well-known Doppler effect which will be discussed later in more detail in Fig.6.

After suitable filtering to remove RF, noise and microphonic components, this audio signal is amplified by V2 and V3 and applied to the grid of the thyratron, V4. Normally, V4 is biased negatively and no plate current flows. When the VT fuze is within optimum striking range, the signal is strong enough to fire the thyratron. The gas becomes ionized and the plate resistance drops to a very low value. Then C_F discharges through a 10 ohm resistor imbedded inside the squib - a small capsule containing heat-sensitive explosive. The resulting explosion sets off a more powerful explosion in the detonator which in turn triggers the explosion of the main charge. All this occurs in less than a millisecond.

Sensitivity Pattern

As stated before, the nose cone antenna acts in conjunction with the body of the shell as a dipole antenna. The radiation pattern of a dipole antenna is familiar to radio amateurs and is shown in Fig.4A. This figure shows the pattern in a vertical plane containing the antenna. The complete pattern is in the shape of a torus or doughnut generated by rotating the pattern of Fig.4A 360° around the axis of the antenna. The sensitivity of the antenna as a receiver of RF has exactly the same shape. Thus the net, overall sensitivity pattern of the VT fuze (radiation plus reception) is found by squaring the radiation pattern and thus appears as shown in Fig.4B.

If the shell is mis-aimed so that it will pass over or under the target, the Doppler frequency will progressively de-

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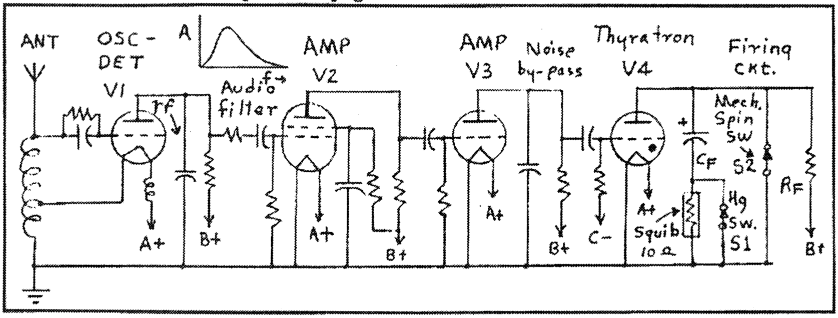

Figure 3. Representative circuit portraying basic elements in a VT fuze.

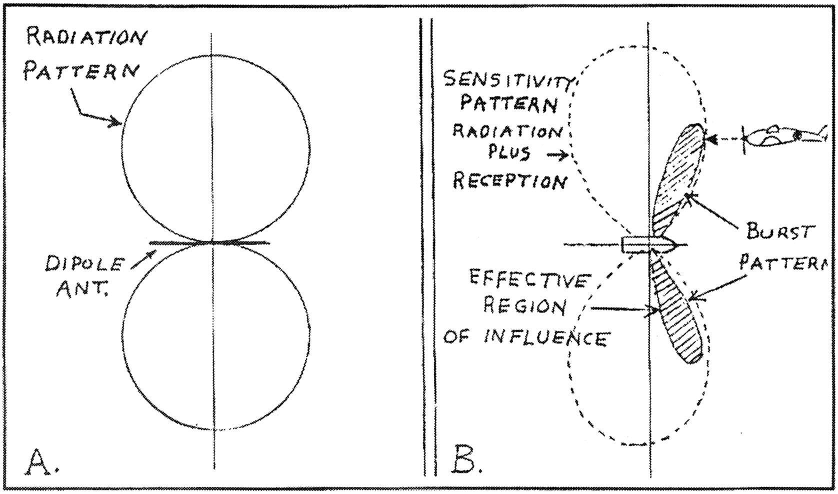

Figure 4. A. Radiation pattern of a dipole. B. Sensitivity and reception. Shaded area - see text.

crease and would drop to zero at the point of closest approach. By properly adjusting the frequency response of the audio amplifier, the effective detection sensitivity pattern can be modified to nearly match the burst pattern of the exploding shell. This is shown by the shaded area of Fig.4B It will be observed that the VT fuze is 'blind' looking 'dead ahead'. Thus if the shell is on a collision course with the target, it will not go off prematurely but will wait till it impacts the target.

Circuit Assembly

Figure 5 illustrates the arrangement of components in a VT fuze. At the top is the antenna protected by the hard plastic nose cone. Just below this is the oscillator-detector coil. Next come the tubes and their associated resistors and capacitors. Each tube is fitted into a rubber shock-absorber. The tubes, resistors and capacitors are laid out flat during assembly and wiring and then rolled up into a cylinder for installation into the fuze. Surrounding all of this is capacitor C_F that fires the squib. Capacitor C_F is rather large (1 uF) and so is formed into a cylinder that wraps around the inner electronics bundle. This capacitor is said[7] to be the first capacitor to use mylar as the dielectric.

After final testing, the electronics bundle is embedded in a potting compound.

The Battery

At the beginning of development, dry batteries were used but these had limited shelf life especially when used in tropical regions. This led to the development of a unique wet battery in which the electrolyte was kept away from the electrodes until the shell was fired. The construction of the electrodes is reminiscent of the old Eveready 'layer-built' batteries. Here the elements are circular discs which fit around a central ampoule which holds the electrolyte. At the instant of firing, this ampoule is smashed open when it is driven against the 'crusher'. The electrolyte then quickly diffuses through the battery electrodes, being driven by centrifugal force.

At the bottom of the stack are 60 elements which give 90 volts for the B supply. Above this are three sets of elements connected in parallel to provide filament current. Finally, the top five elements provide 7.5 volts bias for the thyratron.

In bombs dropped from aircraft and those attached to rockets, the power source is an AC generator attached to a wind-driven propeller. A rectifier-filter converts the AC to DC for the plate supply. The filaments are heated with AC and special feedback circuits are employed to cancel the resultant AC hum. These bombs differ in several other aspects and space does not permit further discussion. See references 2 and 4 for more details.

The Doppler Effect

The Doppler effect [4,5] was mentioned earlier. This is explained in more detail in Fig. 6. In simplest terms, V1 acts as both a radio transmitter and a regenerative receiver. A beat note between the sent and received signals will occur in the plate circuit of V1 and build up in amplitude as the missile approaches the target. In the sample calculation shown in Fig. 6, if the relative velocity (missile to target) is 500 m.p.h. and the oscillator frequency is 160 MHz, then the Doppler frequency will be 238 Hz. This signal is amplified by V2 and V3 and used to trigger V4. By proper adjustment of amplifier gain and thyratron bias, the fuze can be programmed to detonate when the shell comes close enough to the target to be effective. (See section on sensitivity testing).

Safety Devices

The shell shown in Fig. 5 has several safety features built-in which greatly reduce the possibility of accidental or premature explosion. For example, if a gunnerman accidentally drops a shell onto the steel deck inside a gun turret and the capsule holding the battery electrolyte breaks, the shell must not be allowed to explode. And if the enemy invents a countermeasures device designed to detonate the shell immediately after it leaves the canon, a time delay needs to be incorporated so that the shell will be a safe distance away from the ship before it is fully armed. The safety devices take the following forms:

1. The batteries are not activated until the shell is fired. The ampoule breaks and centrifugal force diffuses the electrolyte.
2. The mechanical spin switch shorts C_F and prevents it from charging until the shell is rapidly rotating.
3. It takes time for C_F to charge sufficiently to fire the squib.
4. A mercury switch shorts the squib until the shell is rapidly rotating.
5. The powder train between the squib and the detonator is not aligned until the shell is spinning.

Sensitivity Testing

How do you test a VT fuze to make sure its sensitivity is properly adjusted so it will detonate at the desired distance from its target? A test firing range was built near Albuquerque, N.M. Two

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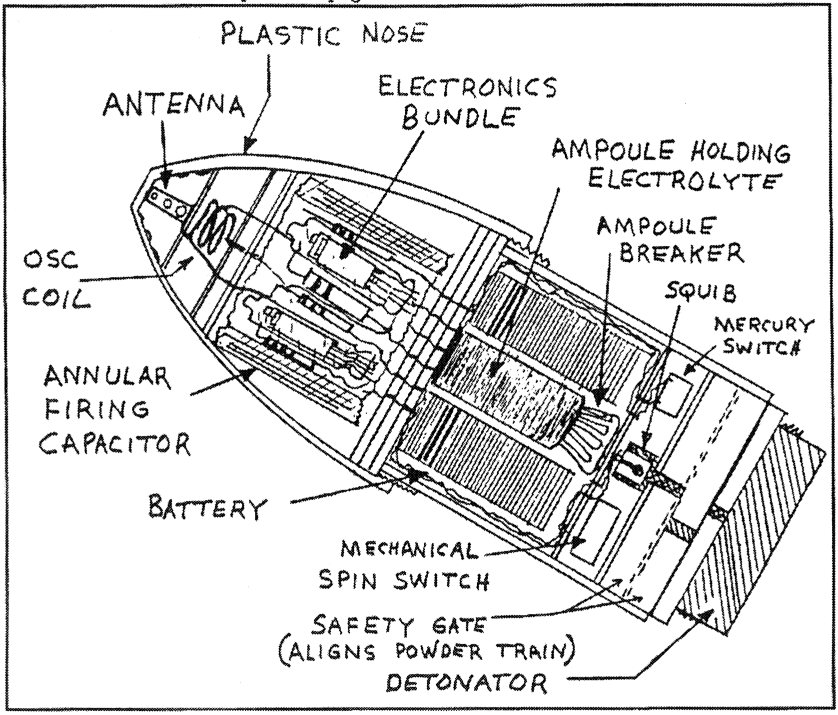
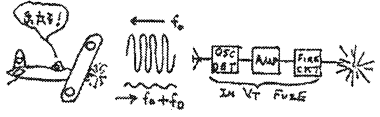


Figure 5. Cross-sectional view of military type VT fuze.



Let f_o = frequency of Osc. in Mhz.
v_r = velocity of shell relative to the plane in m/sec.
s = distance between shell and plane.
λ = wavelength of rf signal in meters

As the shell travels toward the plane, the phase of the returning signal will change by one cycle (360°) when Δs changes by $\lambda/2$

The time taken to execute one cycle is

$$\Delta t = \Delta s/v_r = \lambda/2v_r$$

The Doppler freq is $f_D = 1/\Delta t = 2v_r/\lambda$

If v_r is changed to V_r in mph

Then $f_D = .894\ V_r/\lambda$

and if f_o is, say, 160 Mhz, then $\lambda = 1.875$m.

so that $f_D = .477V_r$.

Example: At $V_r = 500$ mph, $f_D = 238$ Hz.

Figure 6. Showing how the Doppler frequency is found.

tall towers were erected several hundred feet apart. By means of ropes running between these towers, the test airplane was suspended high above the ground. High speed motion pictures could then record such details as average intercept distance, the polar sensitivity and burst pattern and its effectiveness in damaging the airplane.

Uses in World War II

The first use of the VT fuze in Europe was at the Battle of the Bulge. The VT shells exploding about 30 feet above ground cut the tops off all the trees as though a "giant had been at work with his scythe"[4]. The German troops were left with no place to hide. A foxhole or a stone wall is of no use as a shelter when a VT shell explodes 30 feet above you. Without the VT fuze, a shell might burrow into the ground and then explode. If you're in a foxhole, you might be shell-shocked, yet survive. But the VT fuze makes warfare a whole new game. After WW II, General George Patton said that when both sides have the VT fuze, we'll have to devise a new method of warfare.

I was Radar Material Officer on the USS Willard Keith, DD775. When our ship reached the Philippine Islands in May 1945, we received the new 5" AA shells equipped with the VT fuzes. When we got to Okinawa, we were assigned to radar picket station 15, about half way between Okinawa and Japan. Our job was to find the Japanese Kamakazi (suicide) planes by means of radar and then direct the marine aviators circling overhead to intercept and destroy them. In one battle, our ship brought down two enemy planes thanks to the VT fuzes. The VT fuzes are claimed to be five times more effective than the older mechanical fuzes. In the time it takes to load and fire five salvos, a Kamakazi pilot could be flying his plane into your forward boiler room.

Our sister ship, the Hadley, DD774, was at picket station 15 the week before we arrived. She and her support vessels were attacked by about 100 Kamakazi planes. Two or three of these planes managed to plunge through the ensuing barrage and severely damaged the Hadley so that she had to be towed back to Okinawa. Without the VT fuzes, she surely would have been sunk with great loss of life. When I saw the Hadley a few days later, her bridge was decorated by dozens of emblems of the Japanese rising sun flag - one for each plane shot down. We envied her achievement and valor and were thankful that she had rid the sky of so many Zeros. Incidentally, these Kamikaze pilots were given lots of sake just before takeoff, their shoes were wired to the foot pedals and the cockpit canopy was padlocked to foil any last minute loss of courage.

Countermeasures[9]

At least a half-dozen foreign counties now have VT fuzes. Thus it was necessary for the US to develop a device that would protect our troops. This instrument, nicknamed Shortstop, was developed for use in the Persian Gulf war but that war ended just as production got underway. However, some of these devices have now been sent to Bosnia for use there.

Shortstop detects the RF signal emitted by a VT fuze and then radiates a strong false return signal which initiates a premature explosion. The Shortstop device can protect an area at least the size of a football field. It does this by causing the projectile to detonate when it is still 200-300 meters away from the Shortstop unit.

The newest generation of Shortstop devices being developed now will be available in three styles. There will be a small, lightweight soldier's backpack unit. Then there will be a larger unit for use in vehicles such as the Humvees and Bradley Fighting Vehicles. Finally, there will be a still larger unit for field use which will have a tripod mounted antenna.

Conclusion

I think we owe a debt of gratitude to the scientists and engineers who developed the VT fuze. This invention surely helped to shorten WW II and undoubtedly saved the lives of many Americans, including my own!

Acknowledgments

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1. Proximity Fuze: Electronics War Report, Electronics, pg. 110, Nov. 1945

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tried one out. I guess my performance conclusion is that the receiver definitely shows off the attention to detail that went into its design.

At my location, the R-389 seems to be completely free of any sort of detectable intermod product. For example, in broad daylight when the groundwave is the strongest and receiving from a broadside, full-wave wire antenna cut for the center of the broadcast band, there is no detectable product at 1140 kc, the 3rd order mix between KOA at 850 and KLZ at 560 kc (mixing product = (2 X 850) -560). These stations are powerful, longtime Colorado clear channel broadcasters. This test was made with my headphones on, the receiver AGC in the manual gain position, and the RF gain control at full tilt. There is no second-order mixing going on at 1410 kc between these two, either. There is no detectable mix between powerful AM broadcast stations and the receiver's local oscillators. I've never been able to detect any kind of image response (images tune "backwards" from real carriers). Tuning around with the antenna disconnected and the BFO on does not reveal any birdies, even when tuning through the IF! The receiver does not block up or overload when receiving the 50 Kw station in Louisville, Kentucky at 840 kc, the next channel down from the KOA powerhouse at 850. Yet, the receiver is so sensitive that at night in midwinter I can hear foreign carriers between the U.S. AM broadcast allocations, occasionally with a little bit of modulation on them.

At the time I checked it, my R-389 met or exceeded all of the specifications published in the Army technical manual. Due to differences in test equipment configurations and individual experience, interpretation of receiver test results can vary wildly. I'm not going to write up any more numbers relating to equipment performance.

This concludes the R-389 series. Readers wishing to obtain their own copies of the Collins engineering reports should write to Mr. Frank Gentges, (AK4R), 9251 Wood Glade Dr., Great Falls, VA 22066 for further details. **ER**

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7. Letter from H. Selvidge, June 27, 1996.

8. "The Deadly Fuze", Ralph B. Baldwin, 1980, Presidio Press, PO Box 3515, San Rafel, CA 94902.

9. Electronic Umbrella Protects U.S Troops, Bruce D. Nordwall, Aviation Week and Space Technology, p. 90, Feb. 5, 1996.

ALL OUR SAFETY BELTS ARE IN FOR REPAIR--- MAYBE THIS WILL BREAK YOUR FALL