

Proximity Fuze



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The present invention relates to an improved proximity fuze for a tube launched projectile carrying a payload.

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The use of a fuze on a payload carrying projectile has two main functions. Firstly, it protects a handler of the projectile from inadvertent detonation or activation of the payload from when the projectile is manufactured until it is at least several metres from the site from which is was launched. Secondly, it initiates detonation or activation of the payload at a range from a target or from the ground, which range is appropriate to the function of the payload. The appropriate range may be contact with the target, after contact with the target, time from launch or proximity to the target. It is the latter type of fuze, a proximity fuze, to which the present invention relates.

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Current proximity fuzes use a sensing technique known as "doppler" proximity sensing. This technique requires a continuous constant wavelength radio frequency signal to be transmitted by the fuze such that when the projectile approaches its target, the fuze starts to receive its own transmitted signal reflected back from the target. This return or echo signal then interferes with the transmitted signal from the fuze in a sequence of constructive and destructive interference as the projectile gets closer to the target. For a particular reflectivity of target and given that the power of the radio signal transmitted by the fuze and the gain of the receiver which detects the return signal are set, the distance of the projectile from the target when the fuze first starts to detect its own returned transmitted signal can be predicted. Based on this prediction of the proximity of the projectile to the target when the return signal is first detected by the fuze, the fuze can be made to count through successive cycles of constructive interference. The number of cycles of constructive interference that the fuze counts before it activates the payload can thus be set to fix the proximity of the fuze to the target when the fuze activates the payload.

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One problem with this type of fuze is that different targets will have different reflectivities and so the distance from the target at which the fuze first starts to receive a reflected signal will vary from target to target. Accordingly, the distance from the target at which the payload is
5 activated, ie. after the predetermined number of cycles of constructive interference have been counted, will vary from target to target. This reduces the accuracy of such "doppler" type proximity fuzes. This lack of accuracy is generally overcome in the field by firing a first projectile and observing its proximity to the target when it is activated. Then the
10 number of cycles of constructive interference which are counted before activation can be adjusted for subsequently fired projectiles directed at the same target. However, an increasing number of potential applications require a higher accuracy fuze without the need for adjustment prior to use.

15 A further reduction in accuracy is caused because the frequency of the radio signal transmitted by the fuze is not generally as stable as required and so the timing of successive cycles of constructive interference will not be accurate. Further inaccuracies can be added
20 because the ability of the fuze to detect cycles of constructive interference is dependent on background noise levels. Finally, the simple algorithm used by these "doppler" type proximity fuzes and the continuous transmission at one frequency can make them relatively easy to detect and to cause the fuze to malfunction, either by accident,
25 eg. if the ammunition travels through a radar beam or by active sensor jamming measures taken by the enemy.

The aim of the present invention is to provide an improved proximity fuze which can overcome at least some of the problems discussed
30 above. In particular the present invention aims to provide a more accurate proximity fuze which is more difficult to defeat by active sensor jamming measures than the currently used "doppler" type fuzes.

According to a first aspect of the present invention there is provided a
35 proximity fuze for use in a tube launched projectile carrying a payload, comprising:

oscillator means for generating a radio frequency signal which has a varying frequency,
a single antenna means for transmitting the radio frequency signal and for receiving an echo of the radio frequency signal,
5 signal processing means for generating a range signal corresponding to the time delay between the transmission of the radio frequency signal and the receipt of the echo signal,
means for comparing the range signal with a reference signal and depending on the result of the comparison generating an
10 activation signal for activating the payload,
wherein a directional coupling means is used for coupling the radio frequency signal from the oscillator means to the antenna means and to the signal processing means and for coupling the echo signal from the antenna means to the signal processing
15 means.

The transmitted signal is reflected by the target for the projectile or by the ground and the antenna means receives an echo signal, ie. the component of the transmitted radio frequency signal which is reflected
20 off the ground or the target. As the transmitted radio frequency signal has a time varying property, this property of the received signal will be different from that of the transmitted signal by an amount dependant on the rate at which the property of the radio frequency signal varies and the time it takes for the radio frequency signal to travel between the
25 antenna to the target or the ground and back. As the time it takes for the radio frequency signal to travel between the antenna to the target or the ground and back is directly related to the distance or proximity of the antenna (and thus the projectile) from the ground or the target, the difference between the relevant property of the transmitted and received
30 signal can be used to generate a range signal indicative of the distance between the projectile and the ground or target. This range signal can then be compared with a reference signal having the value that the range signal will take when the projectile is in the correct proximity to be activated. When the range signal and the reference signal are the same
35 an activation signal is generated to activate the payload of the projectile,

which could be, for example, high explosives, obscurance material or a lighting flare.

5 The fuze according to the present invention does not rely on the attenuation in amplitude of the echo signal as compared to the transmitted signal as an indicator of the distance it has travelled to reach the target (or the ground) and to return. Therefore, the ranges calculated in the fuze according to the present invention are not dependent on the reflectivity of the target (or the ground). Provided the
10 echo signal has an amplitude sufficient to be received by the antenna means then the comparison of the time varying property of the transmitted signal and the echo signal can be used to generate an accurate indication of the range of the projectile from the target (or the ground).

15 In a first preferred embodiment the amplitude of the echo signal does not alter the calculated range, and the radio frequency signal is transmitted continuously. This preferred embodiment is suitable for use at relatively close proximities, such as 0.5m to 500m.

20 The signal processing means of the fuze preferably comprises mixing means for mixing a part of the transmitted signal with a part of the echo signal to generate a range signal comprising an intermediate frequency signal with a frequency corresponding to the difference between the
25 frequency of the transmitted radio frequency signal and the received echo signal.

The frequency of the transmitted signal and the echo signal are compared by mixing them in a mixing means to generate a intermediate
30 frequency signal with a frequency equal to the difference between the frequency of the transmitted and the frequency of the received signal. The rate at which the frequency of the transmitted signal changes is known and so the difference in the frequency of the transmitted and received signal can be used to calculate the time taken for the
35 transmitted signal to travel to the target (or the ground) and return to the antenna means and accordingly can be used to accurately calculate the

distance of the projectile from the target (or the ground). To simplify the range calculation it is preferred that the oscillator generates a radio frequency signal for transmission by the antenna means which has a linearly varying frequency.

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As the transmitted frequency changes and as the frequency of the received signal required to trigger activation of the payload of the projectile is not the same as the transmitted frequency and also changes, the fuze according to the present invention is more difficult to defeat using active sensor jamming measures than a "doppler" type fuze which transmits and receives a single frequency.

Preferably, the oscillator means comprises a voltage controlled oscillator and preferably the fuze additionally comprises means for generating a linear triangular waveform voltage for driving the voltage controlled oscillator.

In order to reduce the complexity and cost of the fuze a single antenna means is used for transmitting the radio frequency signal and for receiving the echo signal. This allows a directional coupling means to be used for coupling the radio frequency signal from the oscillator means to the antenna means and to the signal processing means and for coupling the echo signal from the antenna means to the signal processing means. A preferred directional coupling means which provides low cost and small size is a quarter wavelength branchline coupler comprising four ports. If such a coupler is used, to save space the oscillator means and the mixing means can be located within an area bordered by the quarter wavelength transmission lines of the branchline coupler.

According to an alternative embodiment of the present invention which is suitable for use at longer ranges, such as 500m to 1km the fuze is adapted to allow operation in a pulsed mode for transmitting a pulsed radio frequency signal. Here the time varying property can be amplitude as the amplitude of the radio frequency signal varies between zero and the amplitude with which the pulses are transmitted. According to this embodiment a series of pluses of radio frequency signal are transmitted,

for example 10 pulses, and the echo signal pulses are received after travelling to the target (or the ground) and back. The time delay between transmitting the pulses and receiving them can be used to determine the range of the projectile from the target (or the ground).
5 Furthermore, the difference in time delay for successive pulses can be used to determine the relative velocity between the target (or the ground) and the projectile. This embodiment is suitable for use at longer ranges because at short ranges the time delay between transmitted and received signals is too short for transmitted and
10 received pulses to be discriminated, that is an echo of a pulse will be received while that pulse is still being transmitted.

This pulsed mode of operation can be used in combination with the frequency varying mode of operation described above. At long range
15 the fuze can initially operate in pulsed mode to determine its proximity to the target (or the ground) and its velocity relative to the target (or the ground) and depending on the calculated distance and velocity can shut down until it is closer to the target (or the ground). Then, at a predetermined shorter range the fuze can be operated in frequency
20 varying mode to calculate its range from the target (or the ground) and activate the payload of the projectile when the calculated range is the desired value for activation of the payload.

According to a second aspect of the present invention there is provided
25 a tube launched projectile comprising a fuze as defined above.

The present invention will now be described with reference to the following Figures in which:

30 Figure 1 shows schematically a transceiver of the proximity fuze according to the present invention.

Figure 2 is a graph of frequency against time showing the radio frequency signal transmitted and the echo signal received by the
35 transceiver of Figure 1.

Figure 3 shows schematically a directional branchline coupler for use in the transceiver of Figure 1.

Figure 4 is a graph of relative power against frequency showing the output of the ports 1 to 4 of the coupler of Figure 3 when a signal is input into port 1.

Figure 5 shows an equivalent coupler to that shown in Figure 3 in a ring formation.

Figure 6 shows schematically a transceiver similar to that in Figure 1 but using the ring coupler of Figure 5.

Figure 7 shows schematically the preferred circuit layout of the transceiver shown in Figure 6.

Figure 8 shows schematically the location of the proximity fuze according to the present invention incorporating the transceiver of Figure 7 in the nose of a tube launched projectile.

In Figure 1 is shown a transceiver according to the present invention which comprises a voltage controlled oscillator (2), a mixer (4), a directional coupler (6) and an antenna (8). The voltage controlled oscillator (2) is controlled by a continuous linear triangular voltage waveform. The oscillator (2) converts the input voltage waveform into a radio frequency signal having a linear frequency sweep (a chirp). The oscillator output signal is divided into two parts by the coupler (6). Part of the signal is directly coupled to and transmitted by the antenna (8) and the other part of the signal is coupled to the local oscillator (LO) port of the mixer (4). The radio frequency signal is radiated by the antenna (8) in a semi-omnidirectional manner and a small part of the radiated power is reflected back to the antenna (8) by a target or by the ground. This returned or echo signal is divided into two parts, one part is coupled to the radio frequency (RF) port of the mixer (4) and the other part is coupled to and terminated in the oscillator (2).

Figure 2 shows a schematic representation of the frequency change with time of the radio frequency signals transmitted and received by the antenna (8), ie. the frequency change of the signals at the LO and RF ports of the mixer (4) respectively. The transmitted signal travels from the antenna (8) to the ground and back at the speed of light which takes a finite and measurable time (δt in Figure 2). The time taken (δt) corresponds to the intermediate frequency (IF) output from the mixer (4). As indicated above, the voltage controlled oscillator (2) is controlled by a continuous linear triangular voltage waveform. This generates a radio frequency output from the oscillator (2) which undergoes a linear frequency sweep (or chirp) between f_1 and f_2 as shown in the full line (10) of Figure 2. The input into the LO port of the mixer (4) (full line (10) in Figure 2) is representative of the frequency transmitted by the antenna (8) and the input into the RF port of the mixer (4) (dotted line (12) in Figure 2) is representative of the frequency received by the antenna (8). The mixer (4) then generates an IF output (represented by difference (14) in Figure 2) which is representative of the difference between the frequency of the LO and RF port inputs. Because the frequency transmitted by the antenna (8) is either linearly increasing or linearly decreasing the difference between the frequency transmitted by the antenna f_t and the frequency received by the antenna f_r at any time t (See Figure 2) is directly and linearly related to the time δt it has taken for the transmitted signal to reach the target or the ground and be reflected back to the antenna, ie. it is directly and linearly related to the distance of the antenna, and thus of a projectile carrying the antenna, above the ground.

The frequency of the IF output from the mixer is directly proportional to the product of the frequency sweep rate (Hz/s) (the rate at which the frequency of the transmitted signal changes with time) and the round trip time (the time it takes for the transmitted signal to travel from the antenna to the ground or target and back to the antenna). The round trip time is equal to twice the range of the antenna (the range is the distance of the antenna from the ground or target) divided by the speed of light. When the intermediate frequency output from the mixer (4) is known then:

$$R = cSf/2d$$

where R = Range (m)

5 c = Speed of light (ms^{-1})

S = Sweep time (s), ie. the time to sweep from f_1 to f_2 or vice versa

f = Intermediate frequency (Hz)

d = Chirp deviation

10 Thus, if the projectile is to be set to activate its payload at a range R , the reference signal with which the intermediate signal from the mixer (4) is compared is the corresponding value for f .

As the projectile gets closer to the target or the ground the time taken
 15 for the echo signal to be received (δt in Figure 2) decreases and so the traces in Figure 2 of the frequency of the transmitted signal (black lines) and echo signal (dotted lines) will move closer together. Thus, as the projectile approaches the target or the ground the frequency of the intermediate frequency signal generated by the mixer (4) will become
 20 smaller. When the intermediate frequency is equal to a reference frequency f as calculated above which corresponds to the range R at which the payload is to be activated, signal processing means responsive to the intermediate frequency signal generates an activation signal that activates the payload.

25 The transceiver according to the present invention avoids the problem of variable ground reflectivity because it compares the frequency of the transmitted and reflected signals and is not dependent on the amplitude of the reflected signal to determine range. The present system is only
 30 dependent on the amplitude of the echo signal to the extent that there has to be a detectable echo signal for the system to work, however, this is a matter of designing the system to cope with the worst case conditions.

35 A branch line coupler (6) as shown in Figure 3 is used in the arrangement of Figure 1, because it is directional, has four ports and

provides at least a 3dB power split. Also, it is relatively insensitive to other components in close proximity and only takes up a small amount of space (preferably a diameter of less than 30mm) as it will have to be located with other components in a small space in the projectile. The
5 coupler (6) operates at a frequency of 2.45GHz with a return loss and isolation of at least -15dB over a range of 100MHz.

The branch line coupler (6) consists of two parallel transmission lines (16) and (18) cross-connected by two quarter wavelength branch lines
10 (20) and (22) which are spaced apart by a quarter wavelength. These transmission and branch lines of the coupler (6) are sandwiched between two pieces of groundplane substrate (34 and 36 in Figure 8) to form a stripline structure, in the conventional way. Power into any one of the four ports of the coupler (6) will be split into two and appear in phase
15 quadrature at the opposing two ports and the adjacent port will receive no output when the coupler (6) is correctly terminated. For example, a signal input into Port 1 of the coupler (6) will be split in two at junction (24) and appear at Port 2 and Port 3 with a relative delay at Port 3 of $\lambda_g/4$ relative to the output from Port 2 and no output will be received at
20 Port 4. The input impedance of the coupler (6) was selected to be 50 Ohms and its modelled output is shown in Figure 4 which shows the variation in the output powers of Ports 1 to 4 with the frequency of a signal which is input at Port 1. It can be seen that the 3dB split required for the coupler (6) is achieved across an adequate bandwidth.

25 As an alternative the coupler (6') shown in Figure 5 could be used. The coupler (6') is equivalent to the coupler (6) shown in Figure 3, except that it is formed into a ring as this gives a space saving.

30 Figure 6 shows a transceiver similar to that in Figure 1 (with like parts having like numerals) which uses a ring coupler (6') as described above in relation to Figure 5. The mixer (4) is a type CDB-9025 mixer available from ST OLETRON CORP and the oscillator (2) is a type MV-146 available from MODCO. A suitable space for the oscillator (2) and mixer
35 (4) was found inside the perimeter of the ring coupler (6') as is shown in the detailed layout in Figure 7 (again with like numerals indicating like

parts) in order to conserve space. The coupler (6') is sandwiched between two pieces of groundplane substrate (34 and 36), and the oscillator (2) and mixer (4) will sit on top of the one of these substrates (36) as shown schematically in Figure 8.

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Figure 8 shows a proximity fuze which uses the transceiver arrangement of Figure 7 located in the nose portion (26) of a projectile. The nose portion (26) can be fitted to the remainder of the projectile (not shown) containing a payload. The nose (26) houses a battery (28) for powering the fuze, control electronics (30), a receive electronics (32) and the transceiver arrangement of Figure 7, including an antenna (8). The control electronics (30) generate the triangular voltage waveform used to drive the voltage controlled oscillator (2). The receive electronics receives the IF signal generated by the transceiver arrangement of Figure 7 and compares it to a predetermined intermediate frequency value which corresponds to the distance from the ground at which the payload of the projectile is to be detonated or activated. When the IF frequency generated by the transceiver arrangement of Figure 7 is equal to the predetermined intermediate frequency value the receive electronics generate an activate signal which is used to activate the payload of the ammunition. The predetermined intermediate frequency value will be set at different levels corresponding to different activation heights suitable for different applications.

It is also possible to make the intermediate frequency at which the activation signal is generated adjustable by an adjustment mechanism, using for example voltage tunable filters (not shown). However, a simpler way to change the range at which the fuze activates the payload is by changing the sweep time (S in the equation on page 11) of the frequency varying signal transmitted by the antenna and keeping the intermediate frequency at which the fuze activates the payload constant. For a fixed intermediate frequency f , the sweep time S will be proportional to the range at which the fuze activates the payload. So for longer ranges the sweep time can be increased and for shorter ranges the sweep time can be decreased.

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The oscillator (2) and mixer (4) are mounted on one of the two groundplane substrates (34,36) which sandwich the ring coupler (6'). The antenna (8) provides at least hemi-spherical coverage in order to detect the ground reliably under all attitude and roll conditions of the ammunition in flight.

The frequency variation of the output of the oscillator (2) with drive voltage is such that the frequency tunes from about 2.4GHz at 5V to 2.7GHz at 10V. The region from 5V to 7V adequately covers the frequency band of interest and the tuning sensitivity within this region is about 90MHz per volt. The linearity of the frequency output of the oscillator (2) in the range of 5V to 7V is around 20% peak to peak, which is adequate for the present application.

The proximity fuze described above is can be used for detonation ranges of between 3 to 15m for high explosive and smoke rounds, at around 80m for illumination flares and obscurance rounds and for cargo rounds.

For longer distances, in which the received signal is separated from the transmitted signal by a time period greater than twice the sweep time (ie. greater than a single period of the triangular waveform used to generate chirp), the fuze according to the present invention is preferably operated in a pulsed mode. In pulse mode the time taken for a pulse of rf signal to be transmitted from the antenna until the echo of it is received can be used to determine the distance of the projectile from the ground. The relative change in time delay for successive pulses can be used to determine the velocity of the projectile in the vertical direction, ie. relative to the ground. The pulse width could be as short as around 2 to 3 microseconds, which would work down to ranges of around 500m. At closer ranges it would not be possible to discriminate between transmitted and received pulses. A series of for example, 10 pulses could be transmitted and received and then the transmission of signals could be switched off for a period dependent on the measured distance and velocity until the ammunition is closer to the ground. After a time delay dependent on the previously calculated range and velocity when

the projectile is close enough to the ground, the transmission of a radio frequency signal would again be started and the fuze arrangement could be operated in intermediate frequency mode (ie. as described above in relation to Figures 1 to 8) to detonate the ammunition at the
5 predetermined height above the target. Switching transmission off for a period would help counteract jamming.

The control electronics (30) shown in Figure 8 can include timers to turn the proximity fuze on and off and to switch between the pulsed
10 operating mode at longer ranges and the frequency varying operating mode at shorter ranges. In pulse mode the control electronics can be used to work out the range of the fuze from the target or the ground depending on the timing of the sending and receipt of successive pulses.

CLAIMS

1. A proximity fuze for use in a tube launched projectile carrying a payload, comprising:
 - an oscillator for generating a continuous radio frequency signal which has a varying frequency,
 - a single antenna for transmitting the continuous radio frequency signal and for receiving an echo of the continuous radio frequency signal,
 - a signal processor comprising mixing means for mixing at least part of the transmitted signal with at least part of the echo signal simultaneously received, to generate a range signal comprising an intermediate frequency signal with a frequency corresponding to the difference between the frequency of the transmitted radio frequency signal and the simultaneously received echo signal,
 - means for comparing the range signal with a reference signal and depending on the result of the comparison generating an activation signal for activating the payload,
 - and wherein a directional coupling means is used for coupling the radio frequency signal from the oscillator to the antenna and to the signal processor and for coupling the echo signal from the antenna to the signal processor.
2. A fuze according to claim 1 wherein the range at which the fuze activates the payload is varied by the changing the sweep time of the frequency varying signal transmitted by antenna whilst keeping the reference signal constant.
3. A fuze according to claim 1 or claim 2 wherein the radio frequency signal has a linearly varying frequency.
4. A fuze according to any one preceding claim wherein the oscillator means comprises a voltage controlled oscillator.

5. A fuze according to claim 4 wherein the fuze additionally comprises means for generating a linear triangular wave form voltage for driving the voltage controlled oscillator.
- 5 6. A fuze according to any one preceding claim wherein the directional coupling means comprises a quarter wavelength branch line coupler comprising four ports.
- 10 7. A fuze according to claim 6 wherein the oscillator means and the mixing means are located within an area bordered by the quarter wavelength transmission lines of the branch line coupler.
- 15 8. A fuze according to any one preceding claim wherein the fuze is adapted to allow operation in a pulsed mode, for transmitting a pulsed radio frequency signal.
- 20 9. A fuze according to claim 8 wherein the fuze comprises means for switching between a pulsed operating mode and a frequency varying operating mode.
- 10 10. A tube launched projectile comprising a fuze according to any one of claims 1 to 9.