Ultra-wideband Radio Fuze Time Domain Doppler Effect Research

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Abstract—The Doppler effect of UWB signal and the influence on Fuze receiver output signal is quite different from the sinusoidal narrow-band signal. It is necessary to find the relationship between the frequency of fuze receiver and the projectile target approaching velocity. The article study the time domain Doppler effect of UWB fuze receiver, derivation the expression of fuze receiver input, output signal, simulation the frequency relationship according to the mathematical model of UWB fuze receiver. The simulation results shows the output signal of the UWB receiver is proportional to the projectile target approaching velocity and input frequency, The output signal of the UWB receiver is inverse ratio to the width of fuze transmit pulse signal.

Keywords—Ultra-wideband fuze; Ultra-wideband signal; time domain Doppler effect; Fuze receiver; projectile target velocity

I. INTRODUCTIONS

Doppler effect first found by Austria physicist Doppler in 1842, the essence of Doppler effect is when there is relative motion between the transmitter and the receiver, oscillation frequency received by the receiver is different from the transmitter frequency. In the radio fuze system, the fundamental reason cause the Doppler effect is that echo signal duration changed compared with the emission signal when there is relative motion between fuze and target[1,2].

For sinusoidal narrow-band signal, the changes of echo signal duration reflects the change of signal carrier frequency. If the transmit signal frequency is \( f_0 \), Velocity of projectile target is \( V \), the frequency of the echo signal is as \( f = f_0 + \frac{2f_0V}{c} \).

\[ f = f_0 + \frac{2f_0V}{c} = f_0 \pm \frac{2V}{\lambda_0} \] (1)

\( f \) is frequency of the echo signal, \( f_d \) is Doppler frequency. If projectile and target is approaching, \( f_d \) is positive value, if projectile and target is apart, \( f_d \) is negative value.

For Ultra wide band(UWB) radio fuze, the frequency band of transmit signal is wide, the \( f \) is not suit for the UWB fuze. Actually, the Doppler effect of UWB signal and the influence on Fuze receiver output signal is quite different from the sinusoidal narrow-band signal[3-5].

II. UWB SIGNAL DOPPLER TIME SHIFT

Assume that the receiver is located at coordinates \( K \), the transmit is located at coordinates \( K' \), the transmitter coordinates move to the right along the x axis at a speed \( v \) relative to the receiver coordinates. As Figure 1 shows.

![Figure 1. Doppler effect](image)

In the transmitter discrete signal process, mark two time points \( t_1 \) and \( t_2 \) on the receiver coordinates \( K \), the corresponding instantaneous wave source of \( t_1 \) and \( t_2 \) is \( x_1 \) and \( x_2 \), the duration of the transmitter signal (the clock according to the coordinate \( k \) ) is:

\[ \eta = t_2 - t_1 \] (2)

\[ x_2 = x_1 + \eta v \] (3)

The starting and ending signal of the receiver \( \xi_1 \) and \( \xi_2 \) (on the coordinate \( K \) ) is:

\[ \xi_1 = t_1 + \frac{x_1}{c} \] (4)

\[ \xi_2 = t_2 + \frac{x_2}{c} \] (5)

\( c \) is velocity of electromagnetic wave.

From \( (4) \)" and \( (5) \)", the duration time of the receiver is:
\[ \varphi = \varphi_1 - \varphi_2 = t_2 - t_1 + \frac{(x_2 - x_1)}{c} = t_2 - t_1 + \frac{(t_2 - t_1)v}{c} \]

\[ \varphi = \eta(1 + \frac{v}{c}) \quad (6) \]

On the coordinate \( K' \),

\[ \varphi = \eta'(1 + \frac{v}{c}) \quad (7) \]

In the radio fuze system, the transmitter and receiver are located in the same projectile, the receiver signal is the target reflection signal, the duration time of signal is :

\[ \varphi = \eta'(1 + \frac{2v}{c}) \quad (8) \]

From “(8)”, when there is relative motion between fuze and target, echo signal

\[ (1 + \frac{2v}{c}) \] duration time changed multiple compared with the emission signal.

The Doppler effect of UWB signal is the change of pulse width and pulse repetition cycle, the pulse width of the echo signal and the repetition cycle is \([6-8]\):

\[ \Delta T' = \Delta T + \Delta T_d = \Delta T + \frac{2\Delta T v_i}{c} \quad (9) \]

\[ T' = T + T_d = T + \frac{2T v_i}{c} \quad (10) \]

If the target is approaching, \( \Delta T_d \) and \( T_d \) is negative, if the target is getting far away, \( \Delta T_d \) and \( T_d \) is positive value.

For UWB signal, if \( \Delta T \) is 1ns, \( v_i = 100 \text{m/s} \) we can calculate \( \Delta T_d = 6.7 \times 10^{-7} \text{ns} \), ignore the distance between the projectile target during the single pulse propagation caused by relative motion, that is \( \Delta T \) change, for point target \( \Delta T' = \Delta T \). But \( T \) is relative large, the distance between the projectile and target can not be ignored, so the pulse repetition period is called UWB signal Doppler effect in time domain, \( T_d \) is called Doppler shift.

Assume the projectile and target is approaching, in the launch of ith pulse, the distance between fuze and target is

\[ \tau = \frac{2R}{c} \]

, because of the ith echo signal pulse interval change to

\[ T'_i = T_i + T_{id} = T_i - \frac{2T v_i}{c} \]

the (i+1)th pulse delay change to

\[ \tau + T'_{i+1} - T_i = \tau - T_{id} \]

, the (i+2)th pulse delay change to

\[ \tau - T_{id} - T_{(i+1)id} \], and so on, the (i+j)th pulse delay change to

as the Figure 2. Shows[9,10].

The UWB radio fuze mainly adopts the way of sampling integral to receive. The basic principle of sampling integral as Figure 3. shows. Trigger sampling pulse generating circuit generates a pulse width is \( T' \), repetition period is \( T \) sampling pulse. When sampling pulse is coming the switch K closed, integrated circuit integral sampling to the input signal, during the sampling pulse interval, switch K break off, the integral circuit keep the result during \( T' \).

![Figure 2](image1.png)

**Figure 2. time domain Doppler effect**

III. INFLUENCE OF TIME DOMAIN DOPPLER EFFECT ON UWB RECEIVER OUTPUT SIGNAL

The time domain Doppler effect will change the relative position of sample pulse, the echo signal submerged in noise will be recovered according several periods.

From the above analysis, the echo signal through the fuze receiver sampling gate by \( T_{id} \), it is mean the sample pulse sampling the single echo pulse by \( T_{id} \) as the sample
As Figure 5. Shows. A period signal
that duration time is $l$, needs $T_d$ period from the
sample pulse start to sample to the end, among them,

$$T_d = \frac{2Tv_t}{c}$$

. The receiver output signal length change to

$$l' \approx MT = \frac{lT}{T_d} = \frac{c}{2v_t} l$$

(11)

From “(11)”, the signal length changed
$\frac{c}{2v_t}$ multiple compared with the past, assume the
output signal waveform not changed, the circuit output signal frequency
$\frac{2v_t}{c}$ multiple compared with the past. As the

(12) shows:

$$f' = \frac{2v_t}{c} f$$

$ f$ is the frequency of input signal, $f'$ is the
frequency of output signal. From “(12)”, the output signal of
the UWB receiver is proportional to the projectile target
approaching velocity $v_t$ and input frequency.

The above analysis is based on the invariance of the
signal waveform. In actual situation, sampling pulse has a
certain width, the echo signal is not constant during the
sampling gate open. so the sampling output signal is an
average of the sampling capacitor. Besides, the balanced
sampling integral circuit cannot fully recover the
amplitude of input signal, the gain is different, the
waveform of output signal maybe changed. The “(12)” is
an approximate relationship.

IV. FUZE TIME DOMAIN DOPPLER EFFECT SIMULATION

Simulation according to the mathematical model of
UWB fuze receiver and the frequency relation of Doppler
effect on the receiver input output signal. The receiver
input signal is fuze echo signal, as Figure 6. and Figure 7.
shows.

**Figure 6. Echo signal time domain waveform**

For the velocity of projectile respectively equal to
100m/s, 200m/s, 300m/s, the fuze receiver output
signal waveform and spectrum as Figure 8. and Figure 9.
shows.

**Figure 8. Output signal time domain waveform**

- **v=100m/s**
- **v=200m/s**
- **v=300m/s**
From Figure 8 and Figure 9, with the increase of velocity of projectile and target, the circuit output signal frequency increases, basically a linear relationship. Compared to Figure 9 and Figure 7, the output signal frequency and the input frequency satisfy the relation

\[
\frac{f'}{f} = \frac{v}{c}
\]

From Figure 8, the amplitude of signal changed with the change of projectile and target velocity, the Figure 10. Shows the amplitude relationship.

**CONCLUSIONS**

The time domain Doppler effect of UWB fuze is different from the traditional sinusoidal narrow-band fuze; it is demonstrated that because of the time domain Doppler effect, the UWB fuze receiver output frequency is proportional to the frequency of input frequency and the projectile and target velocity. Because of the receiver input signal is the fuze echo signal, the frequency of the echo signal is inversely proportional to the width of the pulse.

In conclusion, the output frequency and the input frequency satisfy

\[
\frac{f'}{f} = \frac{2v}{c}
\]

The output signal of the UWB receiver is proportional to the projectile target approaching velocity \(v\) and input frequency. The output signal of the UWB receiver is inverse ratio to the width of fuze transmit pulse signal.

The amplitude of signal changed with the change of projectile and target velocity, the Figure 10. Shows the amplitude relationship.

**REFERENCES**


