

# An improved waveform for multi-target detection in FMCW vehicle radar

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**Abstract.** Frequency Modulation Continuous Wave (FMCW) radar has been widely used in vehicle safety systems now. Many kinds of waveform have been designed to solve the coupling of distance and velocity in multi-target detection. This paper proposes a novel FMCW waveform which contains three sections with same duration in each period. Two sections are up ramps with different slopes and one is down ramp. Two groups of  $N \times N$  values of the distance and velocity can be extracted by implementing  $N$ -point FFT towards one up ramp and down ramp signal. The distance and velocity in the two groups are the same for the real targets, however, quite different for the ghost targets. Compared with traditional waveforms, the proposed waveform in our work has simpler algorithm and less computation, which has been validated by simulations.

## 1. Introduction

Compared with the general radar, LFMCW radar has a large time-bandwidth product, therefore it has high ranging precision and resolution. In addition, it also takes the features of simple structure, small volume, light weight, high immunity to weather and environment, and thus has been widely applied in automotive anti-collision radar, automatic cruise control [1].

Because of the relative motion between radar and target, there is the coupling problem of distance and velocity. The traditional radar transmits the symmetric triangular wave signal, and the distance and velocity parameters of the target are obtained by using the symmetry of the up and down beat signals. But when there are multiple targets, it is difficult to obtain the accurate parameters of the targets because of the false targets. To solve such problems, [2] presented a changeable periods frequency modulated continuous wave radar signal, while [3] proposed a changeable slope continuous wave radar signal. And [4]-[6] also proposed some other waveforms. These methods can solve the multi-target detection problem in eliminating false targets, but they have the problem of large amount of computation and complex algorithm, which will lead to increased cost and poorer performance of the vehicle borne radar.

In this work, a new radar waveform is proposed, which is easy to implement in practice and only need to implement FFT three times.

## 2. Multi-target detection of FMCW Radar

### 2.1 Principle of FMCW radar

The basic principle of FMCW radar is to determine the speed and distance of the target by the frequency difference between the transmitting signal and the receiving signal, and the traditional FMCW signal is shown in Fig.1, where  $f_0$  is the starting frequency of the modulation signal,  $B$  is the modulation bandwidth, and  $T$  is the modulation period. Noting that,  $f_d$  is the Doppler frequency, which can be expressed as  $f_d = \frac{2v}{\lambda} \cdot f_r$  is the beat frequency of stationary target, expressed

as  $f_{\tau} = \frac{4RB}{CT}$ .  $f_+$  refers to the up ramps beat frequency and correspondently  $f_-$  is the down ramps beat frequency which can be expressed as follows:

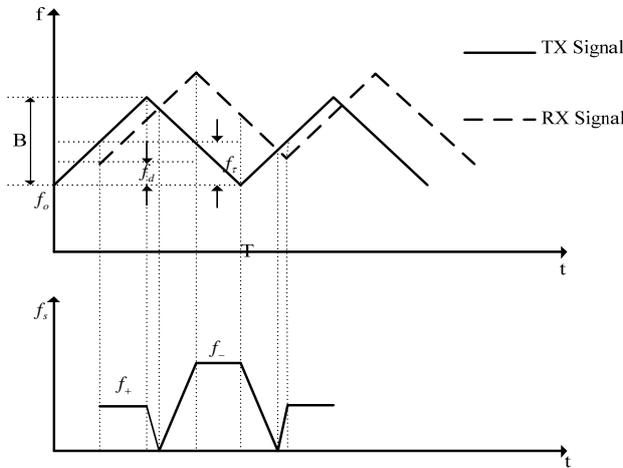


Fig. 1 Principle of FMCW radar for a single moving target using triangular waveform

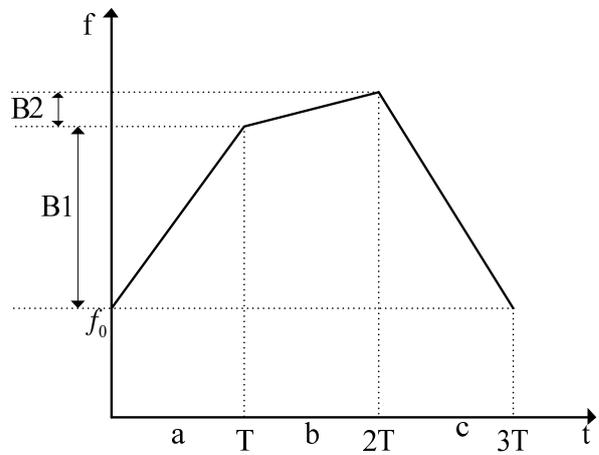


Fig. 2 The proposed radar waveform

$$f_+ = f_{\tau} - f_d \quad f_- = f_{\tau} + f_d \quad (1)$$

Therefore, the distance R and the relative velocity v of the target can be extracted as follows:

$$R = \frac{cT}{8B} (f_+ + f_-) \quad (2)$$

$$v = \frac{c}{4f_0} (f_- - f_+) \quad (3)$$

In the case of detecting a single target, this method is simple and feasible. While in a multi-target situation ( $N$  targets is assumed), there are  $N$  beat frequencies in the up ramp ( $f_{a1}, f_{a2}, \dots, f_{an}$ ) and  $N$  beat frequencies in the down ramp ( $f_{b1}, f_{b2}, \dots, f_{bn}$ ), if the possibility of the combination of these two groups of lines is considered, the  $N^2$  groups of distance and velocity can be obtained. However, only  $N$  out of  $N^2$  are real targets and the rest are so-called ghost targets.

## 2.2. The proposed method

To solve above problem, a new radar waveform is proposed in this work, as shown in Figure 2.

Two segments are up ramps with different slopes  $\mu_1 = \frac{B_1}{T}$ ,  $\mu_2 = \frac{B_2}{T}$  and one segment is down ramp

with the slopes  $\mu_3 = \frac{B_3}{T}$ . According to the matching algorithm, the true distance and velocity of

targets can be obtained accurately. It can not only solve the problem of how to eliminate false targets in target detection, but also only need a simple algorithm which can reduce the amount of computation effectively.

For section  $a$ ,  $b$  and  $c$ , the following expressions can be obtained from (1)

$$f_{a+} = f_{a\tau} - f_{ad} \quad f_{b+} = f_{b\tau} - f_{bd} \quad f_{c-} = f_{c\tau} + f_{cd} \quad (4)$$

The value of the distance and velocity are obtained by section  $a$  and  $c$ ,

$$R_1 = \frac{c(f_{a+} + f_{c-})}{2(\mu_1 + \mu_3)} \quad v_1 = \frac{c(\mu_3 f_{a+} - \mu_1 f_{c-})}{2f_0(\mu_1 + \mu_3)} \quad (5)$$

In the same way, the value of the distance and velocity are obtained by section  $b$  and  $c$ .

$$R_2 = \frac{c(f_{b+} + f_{c-})}{2(\mu_2 + \mu_3)} \quad v_2 = \frac{c(\mu_3 f_{b+} - \mu_2 f_{c-})}{2f_0(\mu_2 + \mu_3)} \quad (6)$$

In the signal processing, 1024-point FFT of section *a*, *b* and *c* are implemented respectively. According to (5) 6  $N*N$  groups of value of the distance and velocity are obtained by section *a* and section *c*, then  $N*N$  groups of value of the distance and velocity are obtained by section *b* and section *c*. Generally, the two group values of distance and velocity for the ghost targets will be different. As for the real targets, the same values of distance and velocity can be obtained in the two groups. Therefore, as long as we find out coincident values from the two group values, the accurate distance and velocity of real targets can be obtained. A summary of this algorithm is shown in Fig. 3.

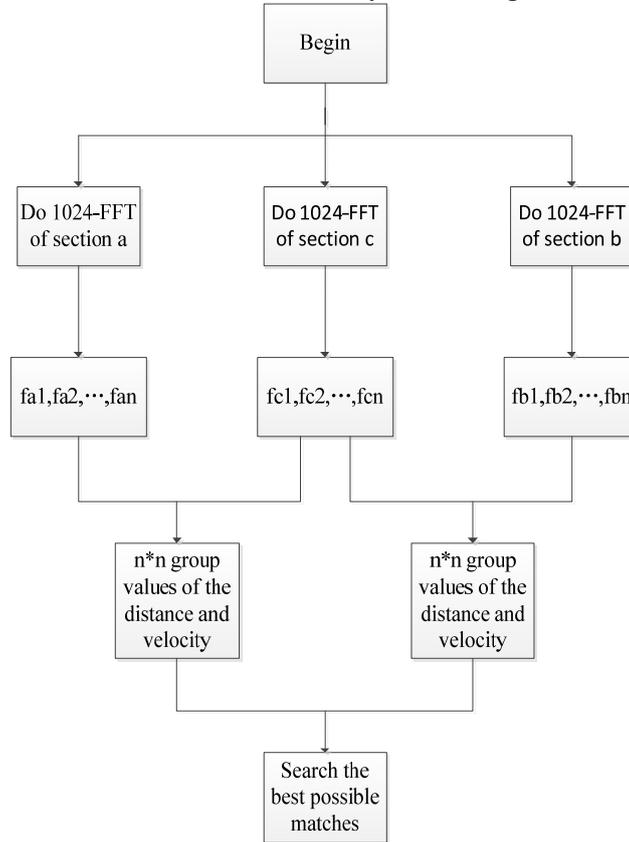


Fig. 3 Algorithm implementation process

### 3.Results and Discussion

The proposed algorithm was simulated in Matlab and the simulation parameters are listed in Table 1, while the targets parameters are listed in Table 2.

Table 1 Simulation Parameters

Parameters	Values	Units
fo	24	GHz
B1	200	MHz
B2	50	MHz
T	5	ms

Table 2 Targets Parameters

Target	Distance (m)	Vlocity (m/s)
1	10	10
2	20	-15
3	45	25
4	70	-35
5	85	-10

Fig. 4 shows the simulation results of multi-targets detection using the proposed algorithm. The horizontal axis is the range and the vertical pole is the velocity. We can see that the real targets can be found and the ghost targets were canceled effectively. In addition, the benefit of the proposed scheme is that it can find out the real targets quickly with only slight computational complexity (three sections) rather than huge computational complexity.

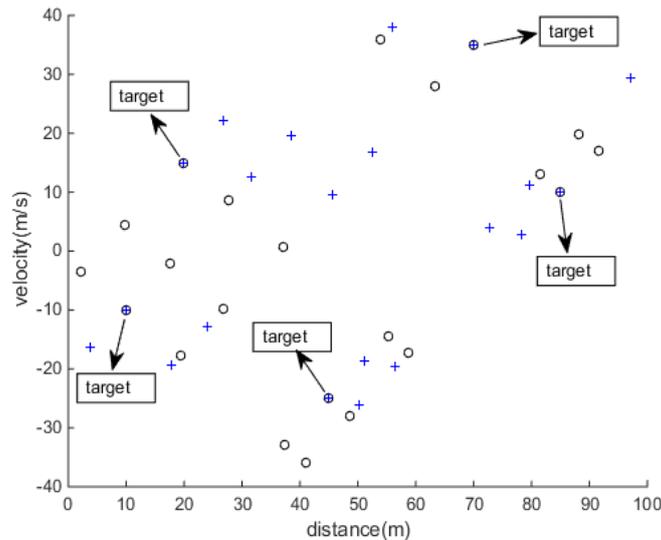


Fig4. The simulation results

#### 4. Conclusion

A novel waveform and multi-target detection algorithm applied to FMCW automotive radar is proposed in this paper. The simulation results show that the real targets can be obtained accurately and this method cancels all the ghost targets simultaneously.

The improved method takes the features of simpler algorithm, less computation and higher efficiency, and is convenient for engineering realization, which indicate a possible potential application in FMCW radar technology.

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