New Implementation of the Correlation Function of the PN Code for Application in Automotive Radars

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Abstract - This paper presents a new method for implementing the shifting of the PN code to calculate the correlation function which is used to measure the target range in the spread spectrum automotive radar. The new method results in higher resolution without increasing the chip rate of the PN code (which necessitate increasing the bandwidth). This new method has the facility of variable resolution without increasing the complexity of the system.

1. Introduction

Over the past few years, automotive radars have become an important and interesting area for microwave and millimeter wave (MMW) applications [1]-[12]. They not only have the huge market potential of the automotive industry but also will play an important safety role in the future intelligent vehicle highway systems (IVHS). The spread spectrum modulation has a number of features that make it easy to achieve the following characteristics: Accurate distance measurement, separation and detection of multiple vehicles located in the range direction and interference eliminating capability. For the reasons mentioned above, the spread spectrum modulation was considered more suitable for automotive radar, and it was used in the development of the millimeter-wave radars. The target range is evaluated by the correlation between the received PN code and the reference one. In order to calculate the correlation function we need to shift the reference PN code with a known step. The resolution in measuring the distance as well as the required processing time will be affected by the selection of the shifting step of the reference PN code. There are two main methods that have been used to implement the shifting of the PN code. The one chip shifting [1]-[10] and the sliding correlation [11],[12]. Both of the above two methods have some limitations as will be explained in the next section.

In this paper a new method was developed for implementing the shifting of the PN code which overcomes the limitations of the previous methods. In this new method we can achieve high resolution without increasing the bandwidth. On the other hand the complexity is less than that of the sliding correlation. This new method also has the facility of variable resolution, which is required to switch the radar system from detection phase to tracking phase. In [10] three different chip rates have been used for this purpose, which increases the complexity of the system.

2. Previously Used Methods

The distance from the vehicle to the target is calculated from the traveling time of the reflected wave. This distance R is calculated by [13]:

$$R = c.T_d/2 \tag{1}$$

Where c is the speed of light and T_d is the traveling time to the target and back. To measure the distance, therefore, it is necessary to measure T_d. The traveling time T_d is evaluated by the correlation between the received PN code and the reference PN code. The correlation function for the PN codes has been shown to be given by:

$$R_{cc}(\tau)=\frac{1}{T}\int_{-T/2}^{T/2} C_{RX}(t-T_d)C_{RE}(t-\tau)dt \tag{2}$$

Where $C_{RX}(t-T_d)$ is the received PN code, $C_{RE}(t-\tau)$ is the reference PN code (shifted by an amount τ) and $T = F_{ch}/N$ (where, F_{ch} =chip rate of the PN code, N= the length of the PN code) is the reciprocal of the code repetition frequency. In order to calculate the correlation function we need to shift the reference PN code with a known step τ_s. The resolution of the measured distance ΔR as well as the processing time T_s will be affected by the selection of the shifting step of the reference PN code as follows: The resolution of measuring the distance is given by.

$$\Delta R = \pm c\tau_s/2 \tag{3}$$

The corresponding processing time is given by.

$$T_s = (T_d/\tau_s)\,(N/F_{ch}) \tag{4}$$

It is clear from (3) and (4) that the resolution of measuring the distance is inversely proportional to the shift step while the opposite applies for the processing time. There were two commonly used methods for implementing the shifting of the reference PN code. Each method has its advantages and disadvantages. These methods are:

A. The One-Chip Shifting Method

In this method the shifting step $\boldsymbol{\tau_s}$ is equal to the reciprocal of the chip rate F_{ch}

$$\tau_s = 1 / F_{ch} \tag{5}$$

There is a number of techniques that have been used to implement this type of shifting the reference PN code [1-10]. Whatever the technique used to implement this type of delay between the two PN code we can obtain a shifting step $\tau_s=1/F_{ch}$, which is equal to one chip. This means that in order to improve the resolution of measuring the distance and reduce the processing time we need to increase the chip rate. The disadvantages of this method are. 1-) the resolution is limited by the bandwidth (the required bandwidth of the this radar system is $BW= 2F_{ch}$) that can be handled by the modulator/demodulator in the IF stage, while still preserving phase and amplitude balance. 2-) increasing the noise corrupting the radar signal due two increasing the bandwidth. 3-) fixed resolution (except if we have variable chip rate as in [10], which will be lead to complex implementation).

B. Sliding Correlation

Another approach has been suggested in [11],[12] to measure the distance more precisely than the one chip shifting method. The technique proposed in this contribution is based on the sliding correlation [14], in which the clock frequency of the reference PN code on the receiving side was set slightly lower than that of the modulation PN code on the transmitting side. The step of shifting by using this method is then given by:

$$\tau_s = \frac{N}{F_2} - \frac{N}{F_1} = N\left(\frac{F_1 - F_2}{F_1 F_2}\right) \tag{6}$$

Where N is the length of the PN code, F_1 is the clock frequency of the received PN code and F_2 is the clock frequency of the reference PN code. On the other hand the processing time is given by

$$T_s = T_d \frac{F_1}{F_1 - F_2} \tag{7}$$

Using the sliding correlation will give better resolution without increasing the required bandwidth for the system, because the resolution obtained by this method is not depending directly on the chip rate of the PN code. It depends on the difference in frequency between the two PN codes ($F_1 - F_2$). The difficulty in the sliding correlation is that in order to have better resolution we need to implement two slightly different, synchronized and stable clock frequencies, which is not an easy job in practical situations. In the same time it faces the same problem of the previous method that the resolution is fixed.

3. Fraction of chip shift method

The automotive radar requires that the distance between the vehicle equipped with the radar and the target can be measured as accurate as possible. If the reference PN code is shifted by the time interval equal to one chip, as indicated by the one chip shifting method, and the correlation is calculated at the same time, the absolute accuracy of the distance measured is affected by the resolution of a distance corresponding to one chip.

In our proposed method, instead of generating the reference PN code using shift registers we will store a sampled version of the transmitted PN code in a memory, which has the facility to make a circular shift by one sample. The samples will be represented in the memory using one bit per sample. The number of stored samples per one chip is proportional to the required resolution of the system. At the same time, the rate of reading out the stored PN code is also proportional to the required resolution of the system. For example, if we need a resolution equal to ¼ chip, then we need to represent each chip with 4 samples and the rate of reading out the stored PN code will be in this case $4*F_{ch}$, where F_{ch} is the chip rate of the transmitted PN code. Table 1 shows this schematically for a code length N=7 and number of samples per chip m=4. The shifting step by using this method is given by:

$$\tau_s = 1 /(m F_{ch}) \qquad (8)$$

where m is the number of samples per one chip of the PN code. Then the resolution in measuring the distance becomes $\Delta R = \pm [0.5 (1/mF_{ch})*c]$ and the processing time reduces to $T_s=m*N*T_{d.}$ By using this technique we are able to achieve high resolution without increasing the required bandwidth of the system. We can implement this method by different techniques, as indicate the block diagram in Fig.1.

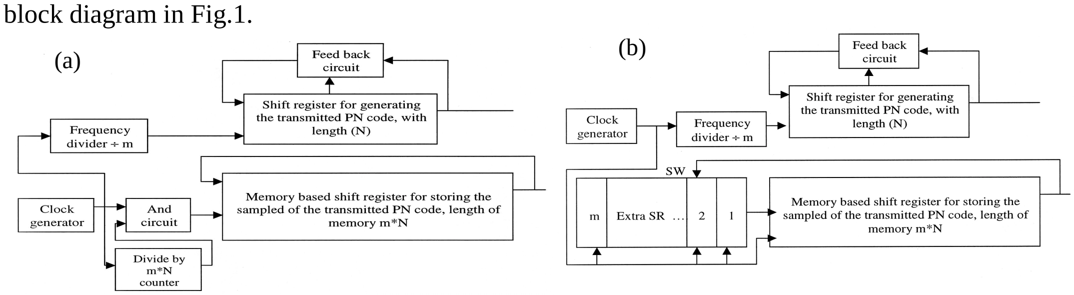

Fig.1. The block diagram of the implementation methods

Fig. 1-a indicates the block diagram of the first method for implementing the delay of the reference PN code. In this method the clock frequency of the reference PN code is blocked for one clock pulse each time the complete pattern is read out from the memory or every m*N clock pulse. This will be equivalent to a continues delay of one sample between the two PN code. The achieved resolution is then equivalent to $1/mF_{ch}$. If we need to change the resolution we can block the clock frequency for more than one clock pulse. By this way we are able to achieve variable resolution. Fig.1-b indicates the block diagram of the second method for implementing the delay of the reference PN code. In this method the delay between the two PN codes is implemented by inserting extra samples (these extra samples will be 0 bits) through the feed back connection. The number of inserted samples is based on the required resolution. For example if we need a resolution equivalent to $1/mF_{ch}$ then we insert only one sample and if the required resolution is equivalent to $1/F_{ch}$ then we insert m samples. The third method is based on [6], in which we can implement the delay between the two PN codes by changing the initial address of the read out reference PN code.

Tx-code	1				1				1				0				1				0				0			
Re-Code	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0

Table 1. The transmitted pn code (tx) and the stored reference pn code (re).

4. Results

Fig.2 indicates the correlation function implemented using the proposed method, with a chip rate of 50 MHz and m=8 which gives a resolution equal to 2.5 ns in measuring the delay time T_d. Table 2 compares the processing time (normalized to T_d with T_d being equal to 1/450MHz, 2/450MHz,………..,N/450MHz) and the required bandwidth for the above three methods. We assumed a resolution of 33 cm and a length of the PN code of 1023. From table 2 we found that the proposed method can achieve the required resolution without increasing the bandwidth. There is however a slightly increase in the processing time compared with that of the sliding correlation.

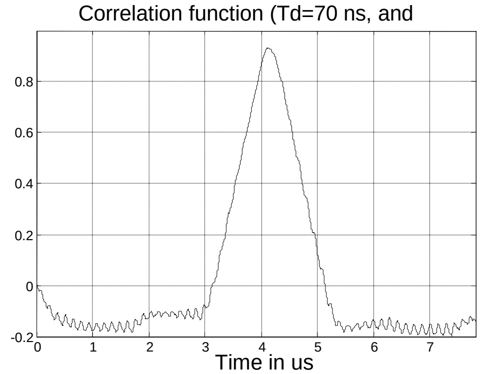

Fig.2. The implemented correlation function using the proposed method

Shifting method	Normalized Processing time	Bandwidth (MHz)	Chip rate (MHz)
One chip shift	1023	900	450
Sliding correlation	16666.67	100	50, 49.997
Fraction of chip shift	8184	112.5	56.25

Table 2. Comparison between the different methods of pn code shifting:

5. Conclusion

A new method for implementing the shifting of the PN code has been proposed. The new technique leads to increasing the resolution in measuring the target range without increasing the required bandwidth. Furthermore a variable resolution can be achieved which is considered as an important requirement to switch the radar system from the detection phase to the tracking phase.

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7. References

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