Probability Analysis of Pulse Compression Integrated with Matched Filter and Range Doppler Map by Using Eigenwaveform Scheme

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ABSTRACT

It is a primary issue of how to increase target detection in terms of radar waveform design, transmitted-received system, and back-end process. In literatures, Eigenwaveforms are the optimum transmit waveform in terms of highest return energy while the pulse compression techniques are used widely in radar system. The motivation of this research focus on the direction that how to integrate the pulse compression, matched filter and the optimum eigenwaveform and jointly apply to Range Doppler Map to enhance the detection rate of range and doppler shift.

Keywords: eigenwavefrom, pulse compression, matched filter, Range Doppler Map

脈波壓縮整合匹配濾波器及 Range Doppler Map 技術應用特徵波型之偵測率分析

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摘　　要

對於如何提升目標偵測率一直是雷達領域的重要課題，波型設計、收發系統設計及後端處裡都是重要關鍵技術。特徵波型在回波能量上是最佳波型，而脈波壓縮技術普遍應用於雷達系統，脈波壓縮整合匹配濾波器及特徵波型應用於 Range Doppler Map 技術在同時偵測目標距離及都卜勒頻移時的偵測正確率提升效果為本研究之重點。

關鍵詞：特徵波型，脈波壓縮，匹配濾波器，Range Doppler Map

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I. INTRODUCTION

Detecting and identifying the target are primary issues in radar systems, the value of return signals or energy is a very important aspect, it will determine that whether radar system detected even to identify target or not. Eigenwaveform is the optimum waveform in the in the field of received energy that it compares with rectangular waveform and wideband waveform, which are usually used in radar systems [1-3]. Eigenwaveform also is an adaptive waveform, eigenwaveform can be designed with any type of target which have various energy distributions in frequency domain [4].

Pulse compression with barker sequence could provide gain, which was related to the length of barker code, and decreased the inference by noise or side lobe. Pulse compression also well combined advantages of longer detection range of broad pulse width wave and higher range resolution of narrow pulse width wave together. Matched filter used widely in pulse compression, and Range Doppler Map was used to show the range and doppler shift of target. In this paper, integrate all the techniques into a new scheme, and improve the performance of detection rate.

II. EIGENWAVEFORM

The earlier target showed in radar screen was a point due to the lower radiation frequency or poor range resolution, targets were identified only with its size of the point and called point target, as the progress of radar the response of target was composed of many points. Targets could be easily identified by the size, length, even shape of points, the target with many points also known as extended target.

Return signal **s** was convoluted by complex type discrete target response **h** and transmit waveform **x**, those lengths both are 31 and the equation given by

$$s = h_{31\times1} * x_{31\times1}$$

Return signal and its Hermitian matrix of being equal to energy of return signal, it given by

$$E_s = s^H s$$

Then use convolution matrix H to replace target response **h,** N is the length of **h** and equation given by

$$\mathbf{H} = \begin{bmatrix} \mathbf{h} & 0 & 0 & 0 \\ . & \mathbf{h} & 0 & 0 \\ . & . & \mathbf{h} & .. \\ . & . & . & \mathbf{h} \end{bmatrix}_{(2N-1)\times N}$$

There has an example of convolution matrix, b is [1; 2; 3] and c is [4; 5; 6], the result of convolution b and c is [4; 13; 28; 27; 18], the equation is shown by

$$\begin{bmatrix} 1 \\ 2 \\ 3 \end{bmatrix} * \begin{bmatrix} 4 \\ 5 \\ 6 \end{bmatrix} = \begin{bmatrix} 4 \\ 13 \\ 28 \\ 27 \\ 18 \end{bmatrix}$$

there uses convolution matrix to replace the original vector and show how do convolution matrix **H** work.

$$\begin{bmatrix} 1\,0\,0 \\ 2\,1\,0 \\ 3\,2\,1 \\ 0\,3\,2 \\ 0\,0\,3 \end{bmatrix} \times \begin{bmatrix} 4 \\ 5 \\ 6 \end{bmatrix} = \begin{bmatrix} 4 \\ 13 \\ 28 \\ 27 \\ 18 \end{bmatrix}$$

and target autocorrelation matrix $\mathbf{R_h}$ is given by

$$E_s = (h*x)^H(h*x) = (Hx)^H(Hx) = x^H H^H Hx = x^H R_h x$$

Set x equals eigenvector $\mathbf{q_{max}}$ of largest eigenvalue $\lambda_{\mathbf{max}}$ from the target autocorrelation matrix, transmit energy $\mathbf{E_x}$ and the largest eigenvalue equals the maximum return energy $\mathbf{E_s}$ is given by

$$E_s = x^H R_h x = q_{\max}{}^H \lambda_{\max} q_{\max} = \lambda_{\max} E_x$$

Eigenwavefrom is adaptive waveform, it was designed by different type of target, it is better than rectangular waveform and wideband waveform, even though eigenwaveform's transmitted energy always lower than rectangular waveform dues to waveform design [1].

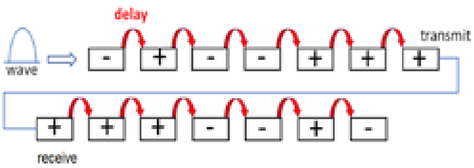
III. PULSE COMPRESSION

Pulse compression includes many schemes such as linear frequency modulation (LFM), phase coding and time-frequency coding etc. This research use phase coding with barker code, barker-13 code is the longest one then ever [5-6], the list of all baker code shown in Table 1 as follows

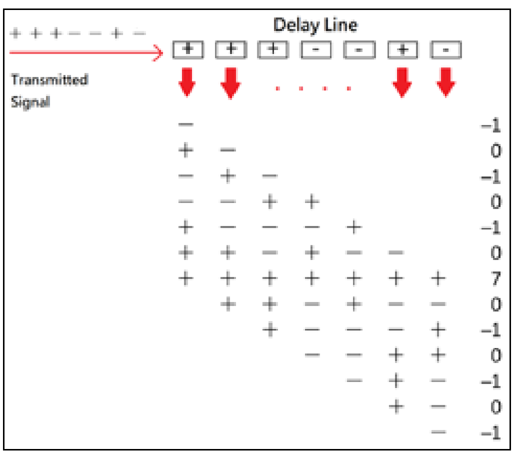
Table.1. Barker sequences length 2 to 13

Length of code	code	Peak-sidelobe ratio(PSLR),dB
2	+ -	6.0
3	+ + -	9.5
4	+ + - + or + + + -	12.0
5	+ + + - +	14.0
7	+ + + - - + -	16.9
11	+ + + - - - + - - + -	20.8
13	+ + + + + - - + + - + - +	22.3

The process of pulse compression with barker-7 codes shown in Fig. 1, waves were transmitted by 7 times, delayed received and accumulated energy in the receiving-end system, the result of pulse compression with barker-7 code also shown in Fig. 2.



(a)



(b)

Fig.1. Transmitted and received process (a) and compression process (b) of pulse compression with barker-7 code

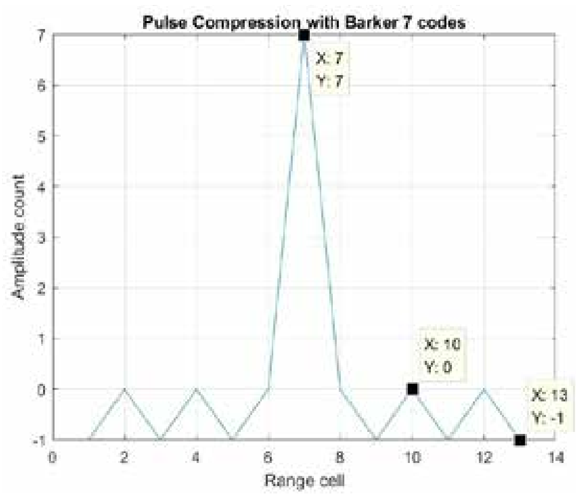
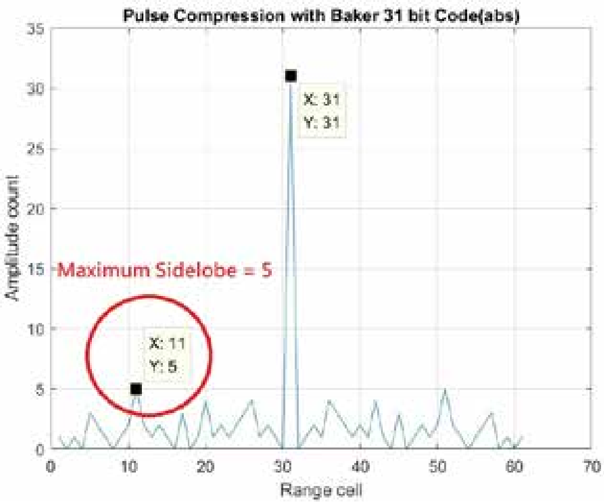


Fig.2. Result of pulse compression with barker-7 code

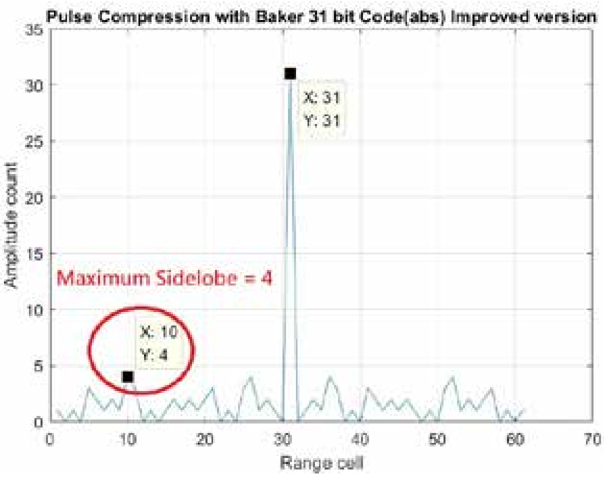
In this paper, the new scheme utilized barker sequence of 31 bits code that due to suit to our pulse compression integrated with matched filter and Range Doppler Map scheme. The barker sequence of 31 bits code[7] is [+ + + + − − − + − + − + + + − − − − + − − + − − + + + − + + −], and the new scheme made a little change to increase its PSLR like[+ + + + − − − + − + − + + + − − − − + − − + − − − + + − + + −], the outcomes shown in Fig.3. The highest side lobe decreased from 5 to 4. PSLR formula is

$$\mathrm{PSLR} = 20\log_{10}\left(\frac{Main\ Peak}{Sidelobe_{max}}\right)$$

Improved version made PSLR grow from 15.8dB to 17.9dB. Further to the longest length of barker code is 13 because their absolute value of sidelobe is 1, but in our case, the maximum absolute value of sidelobe equals to 4, it would make lose PSLR but its length would be more suitable for our scheme.



(a)



(b)

Fig.3. Comparison chart of original(a) and improved barker sequence(b)

The gain of pulse compression lets radar get higher SNR, resolution or PSLR, it means that distinguish between main peak and sidelobe or noise become easier, but the disadvantages make transmitting & receiving-end system more complex and spending more time on transmitting and receiving.

Matched filter is used widely in communication systems, the purpose of matched filter is increasing SNR by comparing with received signal and reverse order expected signal. The process of matched filter is given by

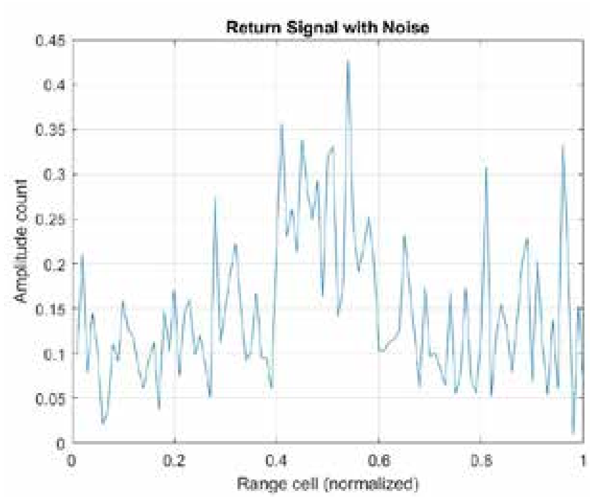
$$y(t) = s(t) + n_{AWGN}(t)$$

and

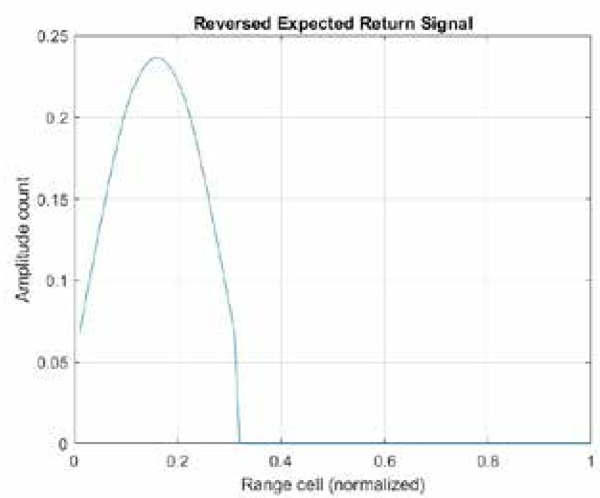
$$MF = y(t) * s_{expect}(t)$$

Where **y(t)** is return signal added additive white Gaussian noise $\mathbf{n_{AWGN}(t)}$, $\mathbf{s_{expect}(t)}$ is reversed expected return signal, **MF** is the result of matched filter.

In Fig.4, noise interferes with received signal and made it hardly be identified, so used the characteristic of matched filter that signals match or not would influence the result shown in Fig.5. find the peak which the convolution of return signal and reversed expected return signal, then to identify the target and its distance.



(a)



(b)

Fig.4. Return signal (a) and reversed expected return signal (b)

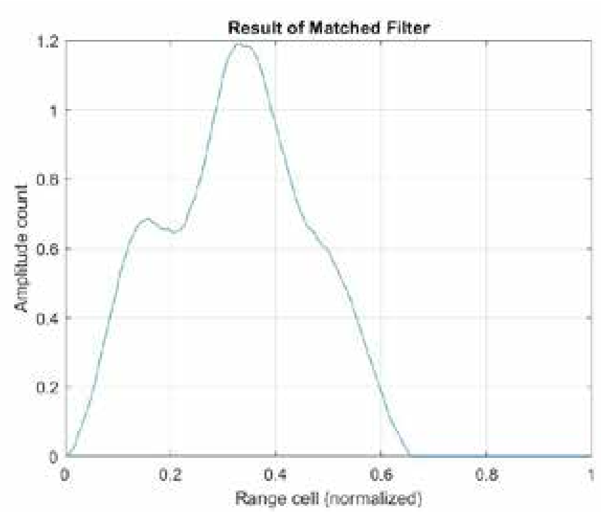


Fig.5. Result of matched filter

IV. RANGE DOPPLER MAP

The advantage of Range Doppler Map is showing target's doppler shift and range at the same time, Range Doppler Map misjudged its doppler shift easily if it lacked information to analyze, so transmitting as much as needed signals would help to judge speed correctly.

In this case, a transmitter sent 31 times transmitted signals which were coded by barker-31 code and used a series of $e^{2j\pi f_d}$ to stand for speed and f_d is doppler shift. Put 31 return signals into Doppler matrix and fast Fourier transform the matrix such as Fig.6, where N is the length of a return signal, the outcome of Range Doppler Map shown in Fig.7.

$$\begin{bmatrix} return\_signal\_1 \\ return\_signal\_2 \\ \vdots \\ return\_signal\_31 \end{bmatrix}_{31xN} \downarrow FFT$$

Fig.6. Doppler matrix

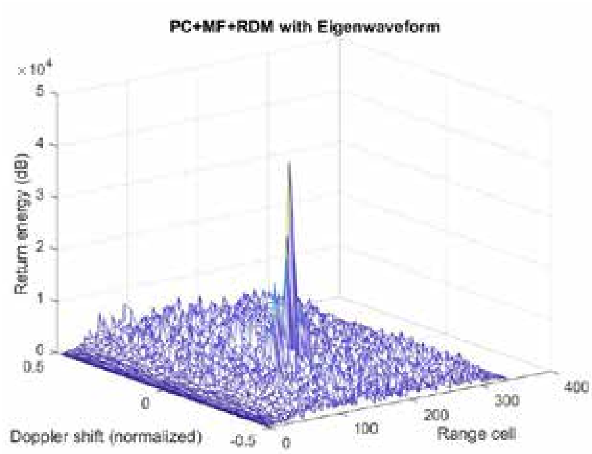


Fig.7. Schematic diagram of Range Doppler Map

V. PROBABILITY OF PULSE COMPRESSION INTEGRATED WITH MATCHED FILTER AND RANGE DOPPLER MAP SCHEME

In this section, designed two schemes to analyze the performance of correct detection rate, one is using only Range Doppler Map with wideband wave or eigenwaveform, the other one is pulse compression integrated with matched filter and Range Doppler Map using wideband wave and eigenwaveform, verify gain of pulse compression and eigenwaveform raising detection rate, and matched filter depressing side lobe and noise or not by compared 2 schemes.

The process of second scheme shown in Fig.8, transmitter sent 31 waves which were coded by barker-31-bit code, received signals would be executed pulse compression and Range Doppler Map at the same time, then intercept the main peak signal of pulse compression and go on to execute matched filter afterwards, lastly, the result of matched filter linked up with Range Doppler Map.

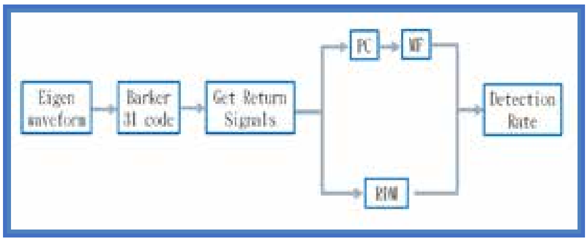


Fig.8. Process of pulse compression integrated with matched filter and Range Doppler Map

SNR was set -15dB to 10dB, energy of target and transmitted waves are same, the threshold was set 80%, the detection rate achieves 80%, that means under circumstance of specific SNR could identify the range and Doppler shift successfully.

5.1 Only Range Doppler Map

The process of only Range Doppler Map scheme is almost same with the other scheme expected procedure of pulse compression and matched filter, the result of this scheme shown in Fig.9, when SNR achieve 9dB, the correct detection rate of using wideband wave equals 82.41%, but the correct detection rate of using eigenwavefrom equals 82.61% and the SNR only have 0dB. In this case, the SNR would be increased 9dB by using eigenwaveform instead of wideband wave, it also means that the transmitter cost less energy to have the same effect on using other waveform, or have a longer detection range.

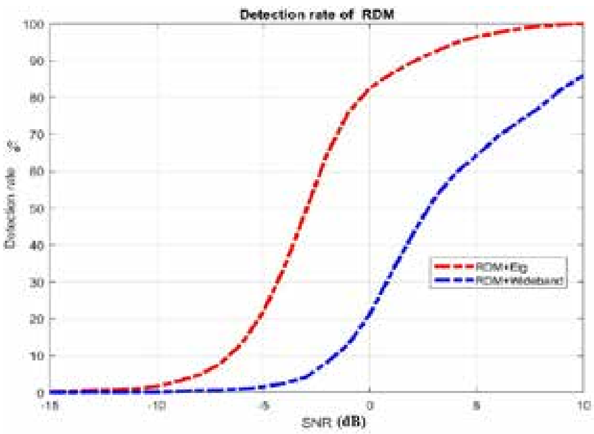


Fig.9. Probability of Range Doppler Map by using eigenwaveform and wideband wave

5.2 Pulse compression integrated with matched filter and Range Doppler Map

In this case, finding the SNR of using wideband is down from 9dB to 4dB when using this scheme instead of only Range Doppler Map scheme, it shows that pulse compression and matched filter enhance the performance of Range Doppler Map.

The correct detection rate of using wideband wave equals 82.41% when the SNR is 4dB, and correct detection rate of using eigenwaveform equals 82.26% when the SNR is -2dB, the outcome shown in Fig.10, and the probability of two schemes shown in Fig.11.

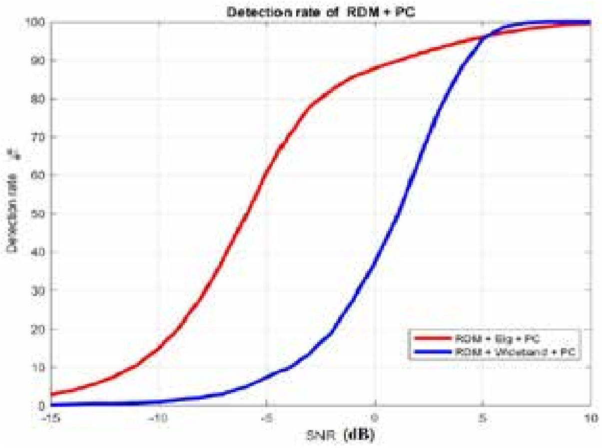


Fig.10. Probability of pulse compression integrated with Range Doppler Map by using eigenwaveform and wideband wave

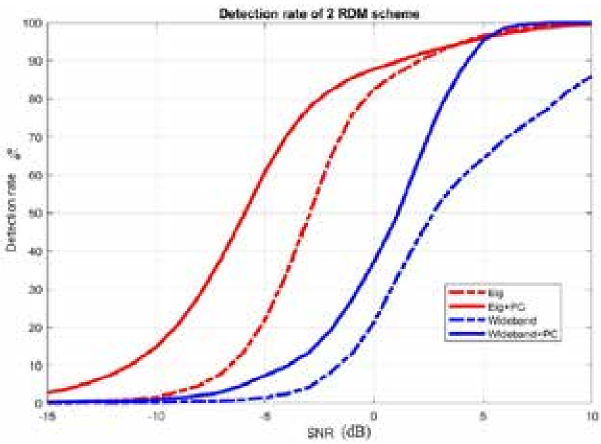
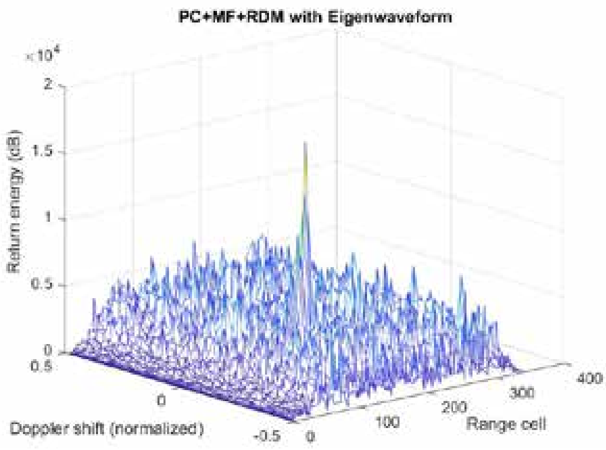
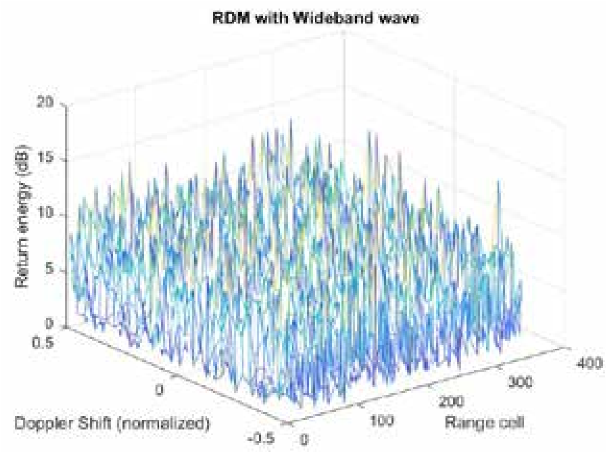


Fig.11. The probability of two schemes

As mentioned above, the best performance of detection rate is pulse compression integrated with Range Doppler Map by using eigenwaveform, and the worst one is an only Range Doppler Map by using wideband wave, the SNR difference between the two schemes is 11dB, in Fig.12, the SNR both equal 2dB, and it could observe the range and doppler shift of the pulse compression scheme more easily and clearly.



(a)



(b)

Fig.12. Range Doppler Map of pulse compression integrated with matched filter(a) and only Range Doppler Map(b)

We have implemented our algorithm by Matlab, and this scheme could be used on national defense, navigation, weather, etc.

VI. CONCLUSION

In this research, utilize the characteristic of extended target to generate eigenwaveform, and explain what is pulse compression with barker sequence, matched filter and Range Doppler Map. This scheme also improves the barker-31-bit code to increase the PSLR from 15.8dB to 17.9dB. Make probability of detecting target correctly more efficient by combining eigenwaveform with pulse compression, matched filter and Range Doppler Map.

Set only Range Doppler Map and pulse compression integrated with matched filter applied Range Doppler Map to compare the gain of pulse compression and eigen waveform, the gains improve the performance of probability greatly, detecting target with lower SNR always is long-term goals in radar system, and it would be more suitable and used widely in radar system or national defense.

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