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Research of the Clutter Suppression for PD Radia Low-altitude Detection

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Abstract: The conventional filtering methods are difficult to meet the demand of ground radar detection performance. Then pulse Doppler technique in high-altitude target detection has shown good performance of clutter suppression. The demand of the clutter suppression ability needed to detect target in a low altitude is illuminated by theoretically analyzing and simulating. And confirms the need of the PD technology to ground-based radar when detecting in low altitude. The inherent problems are discussed which are caused by the application of PD technique to the ground radars and the corresponding solutions are also presented. Research indicates the feasibility of appending the PD technique and the clutter can be suppressed by this method effectively.

Key words: Clutter suppression, PD technique, low-altitude detection

INTRODUCTION

The PD radar (Yang *et al*., 2011) expects to conduct an observations of low-level, must make the high rack meet the requirements of visual range, so the ability of ground-based radar to suppress the clutter must further enhance. Only in this way can detect the weak target effectively when the strong clutter signal background. Its ability to suppress the clutter is very strong and it also has a good performance of target detection. The aforementioned advantages have received more and more social attention. This sort of researches become more and more as well, although the studies about airborne PD radar (Zhou and Wang, 2011; Wang *et al*., 2010a) and Guidance PD radar (Cui *et al*., 2011; Lu *et al*., 2011) have occupied a large portion and the PD technology has also been applied to a few studies on ground radar (Lei *et al*., 2010; Wang *et al*., 2010b; Li *et al*., 2010). all of them discuss the efficiency of the PD technology from many aspects but they don't consider the effective solution to the clutter overlap problem that using PD technology may bring.

On the basis of the main factors of ground radar application, this article restricts the PD system clearly and comes up with an idea to realize that using PD Technology to detect the radars on Low ground altitude and gives out the case how ground-based radar to suppress the clutter with PD technology, finally, concludes whether it can be applied to ground-based radar or not.

ANALYSIS OF PD TECHNOLOGY TO OVERCOME CLUTTER OVERLAP

When the Low-Altitude Detection are using high repetition frequency and computing the clutter data, have to take the clutter overlap problem into account. Because of the clutter overlap may cause the decline of signal-to-noise ratio, an analysis method must put forward higher requirements about the clutter suppression.

The number of clutter overlap, equivalent apparent distance are related with the real distance of the target and pulse repetition frequency. every fuzzy distance point can be calculated by the following expression:

$$R_k = kR_u + R_a (k = 0,1,2\ldots, N) \quad (1)$$

From the above-mentioned expression, The density R_u is the longest undimmed distance and The density R_a apparent distance. The total clutter's echo power is the sum of the echo power of every fuzzy distance point. $C_k(-1 \leq C_k \leq 1)$ was defined as a certain coefficient and it was related with the phase of folded clutter which come from each fuzzy distance point and use P_{ick} to denote the echo power of fuzzy point, if take the clutter overlap into account, the echo power can be expressed as:

$$P_{icmax} = \sum_k C_k P_{ick}$$

If it is consider extreme situations:

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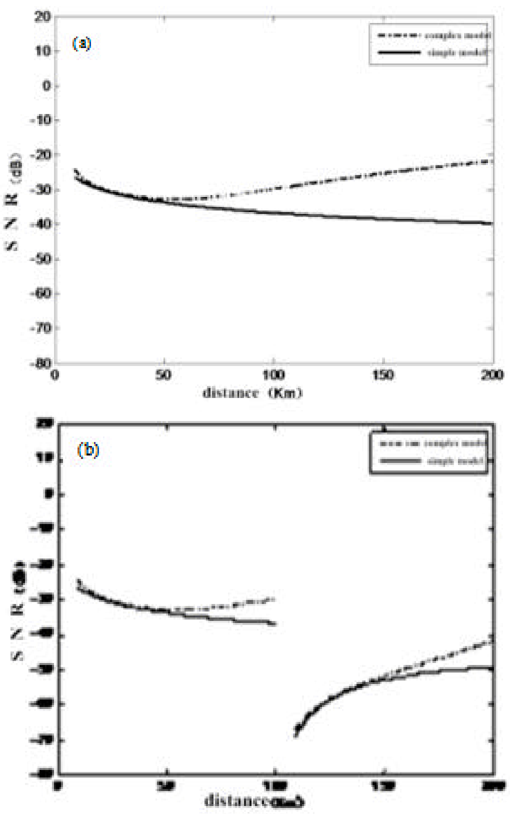

Fig. 1(a-b): Signal to clutter ratio and distance (PRF = 750 Hz), (a) 2 m^2 Target, (b) 0.1 m^2 Target

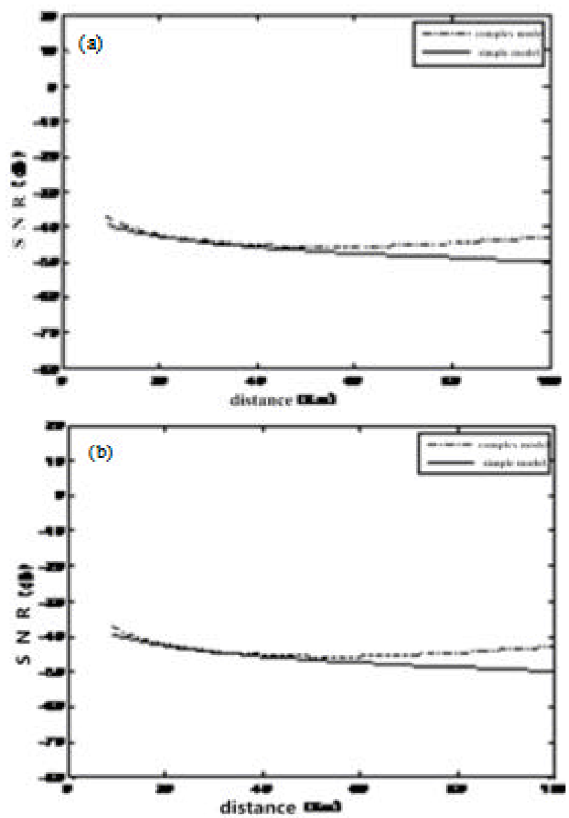

Fig. 2(a-b): Signal to clutter ratio and distance (PRF = 1500 Hz), (a) 2 m^2 Target, (b) 0.1 m^2 Target

$$P_{icmax} = \sum_k P_{ick}$$

according to the expression (1) and the equation of radar range equation, the biggest echo power is expressed as:

$$P_{icmax} = \sum_k P_{ick} = \sum_k \frac{P_t G_t^2 \lambda^2 \sigma_{ck}}{(4\pi)^3 R_k^4 L} \quad (2)$$

In this expression, σ_{ck} is denoted as the average cross-sectional area of radar's fuzzy distance point, P_t is used to denote the transmission power of radar, G_t is to denote the gain of radar antenna, λ denotes the wavelength for radar's transmitting signal and L denotes the coefficient that radar receiving system lose, so the SCR S/C can be calculated by the expression 3:

$$\frac{S}{C} = \frac{P_{is}}{P_{icmax}} = \frac{P_t G_t^2 \lambda^2 \sigma_t}{(4\pi)^3 R^4 L} \Bigg/ \sum_k \frac{P_t G_t^2 \lambda^2 \sigma_{ck}}{(4\pi)^3 R_k^4 L} = \frac{\sigma_t}{R^4} \Bigg/ \sum_k \frac{\sigma_{ck}}{R_k^4} \quad (3)$$

Research declare that the backscattering coefficient is -17.5 dBsm for the clutter, according to the different situation that fuzzy distance and undimmed distance have,the SCR have a close relationship with the change of distance and respectively,they are shown in Fig. 1-3.

From Fig. 1 to Fig. 3, can see when iR_{uamb}~$(I+1)R_{umab}(I+1)$ $(2 \le i \le N-1)$, N is defined as the number of clutter overlapping)are in the range of fuzzy distance,the SCR of target is very low, especially when it is close by iR_{uamb}, the SCR drops rapidly and the target which is Located within this area may be lost.

In addition, considering the influence that the radar transmitted pulse may shelter, the multiple overlapping will be a blind spot on the radar detection range and will have an effect on continuous detecting for radar target. Therefore, when using frequency methods to increase clutter suppression ability, in order to avoid increasing frequency blindly and resulting in the SCR increase sharply, the pulse repeating frequency (PRF) should not be too high.

ACHIEVEMENT OF THE SYSTEM STRUCTURE

The design of ground radar system with PD technology is shown specifically in Fig. 4, the receiver system amplifier, frequency echo signal from the antenna to form intermediate frequency signal. the signal processing system proceed to sample for A/D and interpolate the intermediate frequency signal which comes from the receiver, finally turning it into I, Q orthogonal signal of digital video, to complete the function about pulse compression, Doppler filtering, constant false alarm processing and fuzzy calculating, above all, it can complete the goal of information and control information exchange range between the display terminal and the signal processing system.

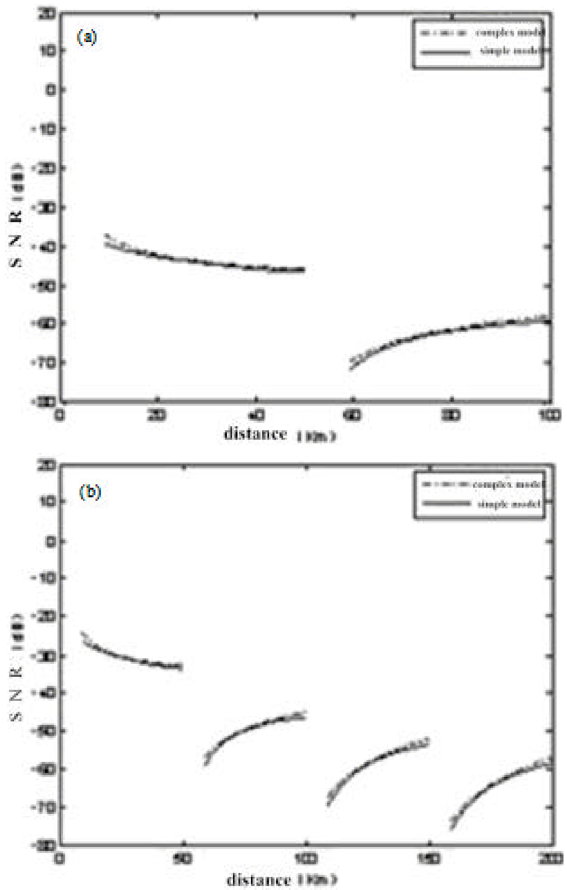

Fig. 3(a-b): Signal to clutter ratio and distance (PRF = 1500 Hz), (a) 2 m^2 Target, (b) 0.1 m^2 Target

At present, in radar signal real-time processing, by adopting the combination of DSP and FPGA/CPLD system structure is a relatively effective way. DSP processor is a kind of instruction set structure, it can realize various algorithm according to the instruction system, its rich I/O resources is conducive to the realization of the function of communication control. However, FPGA/ CPLD is Field Programmable Logic Devices, it can greatly enhance the data transmission speed among digital signal processing board, it also can improve data transmission problem effectively among the DSP. As a result, it can improve the performance of radar signal processor greatly, in addition, it is designed easily and flexibly and it is easy to check, it can quickly modified internal logic again and again among plate, to realize the reconstruction of the system. This system structure is flexible, strong real-time performance, low cost and it can meet the universal demand of radar signal processing.

In the process of system design, not only should consider the hardware complexity of the system implementation in order to guarantee the reliability of the system, but also should realize real-time transformation, reduce the cost of software operation and make the system has good reconfigurable and extensibility. It is the concrete implementation that a part of the function and algorithm should be finished by the DSP have shifted to hardware to accomplish.

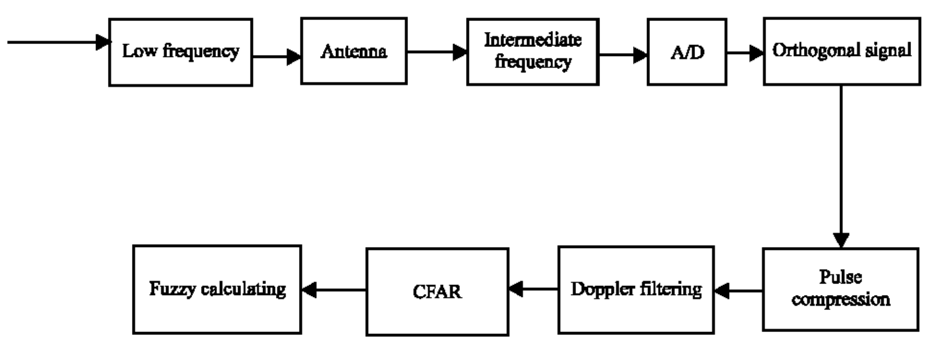

Fig. 4: Simulation flow chart of the system

The basic principle is, the algorithms of signal preprocessing from lower levels need to deal with a large amount of data information and require a high processing speed, but because of its relatively simple operational structure, the FPGA can be used for hardware implementation; the data volume that the algorithm from upper levers is less, but the control structure is relatively complex, so in this case, DSP can be used to implement.

RESULTS OF SIMULATION AND ANALYSIS OF PERFORMANCE

PD radar can realize frequency filter of single line of the Pulse sequence signal spectrum radar pulse, have a capability to distinguish target speed. Compared with the conventional MTI radar, PD radar USES the Digital Signal Processing (DSP) with a low side lobe cancel narrow-band filter group instead of the MTI filter, This way of digital doppler filtering with coherent accumulation, can realize matched filtering of the moving target signal. Extracting the moving target spectral lines falling into different filters, not only inhibits the feature clutter and slow moving clutter, also improves the signal-to-noise ratio and makes the discrimination of speed come true. Compared with MTI filter, the clutter suppression and moving target detection performance of narrow-band filter group of is stronger. Thus, PD system used in the radar system to detect moving targets in strong clutter background will be better.

The PD radar system has a high repetition frequency. The high repetition frequency can improve the ability of suppressing frequency domain clutter and distinguishing the target spectral lines, at the same time, it also can improve the blind speed. The signal-to-clutter ratio of MTD has improved about 40~50 db, surprisingly, the result of theoretical analysis and simulation calculations has shown that the signal-to-clutter ratio of PD system has been raised to 60~80 dB.

For a system using Doppler filter group, by definition, the improvement factor of SCR in the No.k filter is expressed as:

$$I_{fk} = \frac{S_{ok}/C_{ok}}{S_i/C_i} = \frac{W_k^T M_s W_k^*}{W_k^T R_i W_k^*}, \quad k = 0, 1, \cdots N-1 \tag{4}$$

In this expression, W_k is denoted as the weight of the No.k filter, M_s is defined as the covariance matrix of signal, its elements are:

$$M_s(n, m) = \exp\left[j2\pi\beta(n-m)/N\right] \tag{5}$$

In this equation:

$$\beta = N\frac{f_d}{f_r}$$

means normalized frequency, R_i represents the covariance matrix of interference.

Assuming that a low radar frequency is 1300 Hz, under the jagged condition, filter group calculate the improvement factor of ground clutter, sea clutter, sex of clutter and chaff clutter, two kinds of filter group are adopted, One is single notch filter group which formed in deep at zero frequency and another is double notch filter which formed in deep At zero frequency and dynamic clutter frequency. the limit of system improvement factor for transmitter is set to 70 dB, the simulation calculation was conducted for the signal processing of Fig. 4 and according to the expression (4), can get the results of improvement factors that two kinds of filter bank to ground clutter, sea clutter and chaff clutter and cloud and rain clutter are shown in Fig. 5.

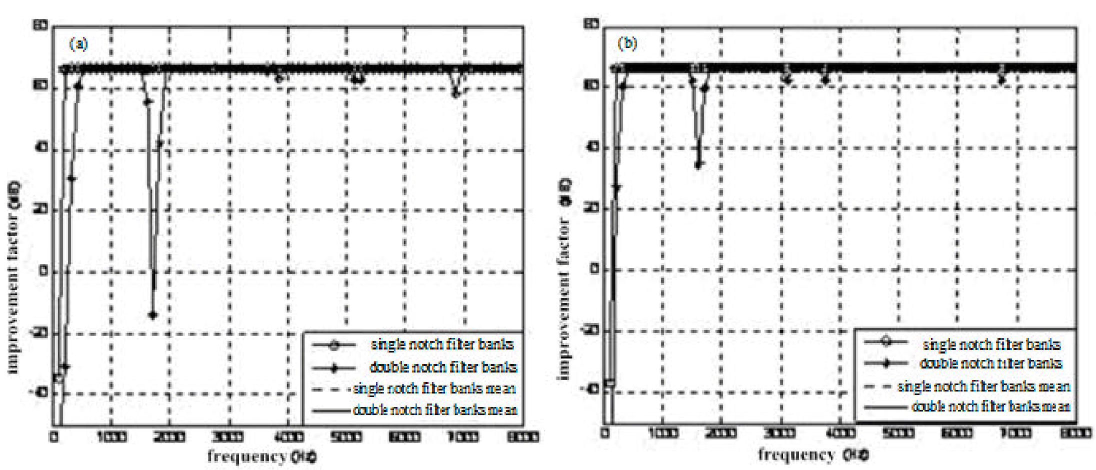

Fig. 5(a-d): Continue

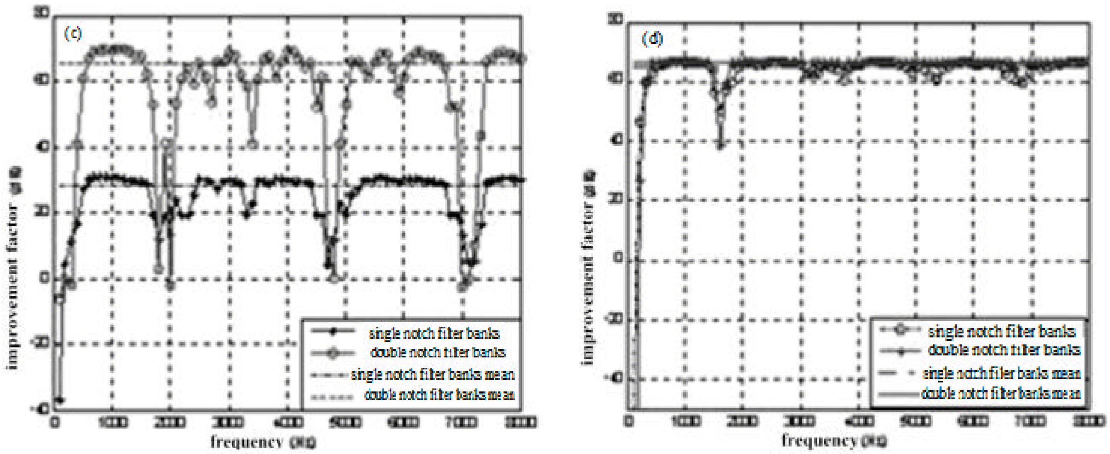

Fig. 5(a-d): PD technology capable of suppressing clutter, (a) Ground clutter conditions, (b) Sea clutter background, (c) Cloud clutter background and (d) Chaff clutter conditions

Table 1: Technology and traditional filter method improvement factor comparison

Filter type	Ground clutter (dB)	Sea clutter (dB)	Chaff clutter (dB)	Cloud clutter (dB)
MTI	40.00			
The optimal weight AMTI	62.62	35.55	56.21	29.03
Non optimal weight AMTI	60.94	36.52	28.55	11.81
MTD	59.66	44.01	30.93	24.15
PD A single notch	66.13	66.49	64.83	28.28
PD Double notch	65.94	65.02	66.04	65.23
Improvement factor	58.30	45.50	37.20	37.20

By analyzing, on this occasion that the area of the little target is less than 0.1 m^2, the flight level below 50 m and the detection range within 100 km, the improvement factors of SCR which comes from various patterns, are shown in Table 1, particularly, MTI mode only gives the limit value of ground clutter situation.

Research can drawn a conclusion from Table 1: When PD technology is applied to detect the low altitude target with ground radar, its clutter suppression performance is obviously superior to the traditional filtering methods, meets the demand of ground radar for detecting low altitude target completely.

CONCLUSION

The research mainly analyzes the realization way that Low Altitude Coverage Radar (LACR) suppresses clutter with PD technology on the ground. On the basis of analyzing the clutter overlap problem that PD technology may bring, corresponding solutions are put forward. This founding was proposed a system implementation approach about LACR using PD technology on the ground and detail the key functional modules of the program. Finally, clutter suppression performance of PD technology is given quantitatively and the feasibility of its application in Low altitude target detection for ground radar are pointed out.

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