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Low-level Wind Shear Echo Signal Modeling

Meng JIA

School of Electrical Engineering, Xinxiang Univertiy, XinXiang, 453003,China
tianshi_cd@163.com

Abstract

This dissertation studies the wind shear field, modeling and simulation of wind shear radar echo. Firstly it introduces the concept of wind shear, classification, causes and its impact on aviation safety of flight. Then it generally introduces wind shear detection technology and signal processing methods. It finishes computer simulations and gets an echo signal velocity spectrum. Finally it develops a software for wind shear echo model simulation. The computer simulation results show that the velocity spectrum data of echo model coincided with the echo model of theoretical analysis. The wind shear echo signals can be simulated based on the simulation software. It can be simple and practical applied to tests of wind shear radar target detection performance.

Keywords*: wind shear radar, wind shear field modeling, echo modeling and simulation.*

1. Introduction

Wind shear refers to a meteorological phenomena, which wind speed, wind direction separately or both simultaneously changes rapidly, especially the microburst below the altitude of 300 meters, it is one of the most dangerous factors when the aircraft is taking off and landing[1].

This part of the simulation is focused on providing the echo signal model, which is used for signal processing algorithms testing. Echo signal model is mainly composed of two parts, the rain echo and ground clutter is simulated respectively[2-3]. The simulation of the basic features include: aircraft position and velocity data, radar parameters input, rain calculation, and the calculation of ground clutter echo.

The echo signal consists of two parts: the ground clutter and wind shear weather echo signals. Ground clutter echo doppler frequency shift mainly comes from the speed of the aircraft itself, and the strength of the echo signal by the radar equation is decided by the reflector on the ground. Wind shear rain echo signal phase depends on the radial velocity of plane and the difference of radial velocity of reflection particles. The signal amplitude is calculated by the radar equation, which is decided by the weather reflection characteristics.

At the beginning of simulation initial position and the antenna pointing is given. As the simulation in process, when a azimuth scan is completed, the position of the aircraft is updated by adjusting the speed of the plane and a scan time[4-9]. The azimuth angle and elevation angle of scanning antenna are adjusted by changing the scan lines. Then we scan the azimuth from the opposite direction. Such simulation is repeated as the scan in process. After each a azimuth scanning, the rain echo and ground clutter data in real-time signal is processed. Then we calculate the risk factors, characteristic parameters extraction and the alarm output.

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2. The Principle of Wind Shear Echo Signal Modeling

2.1 The Doppler Effect

The so-called doppler effect means when the relative motion between waves and observation points exit, the frequency received by the observation point are different from the wave source frequency. When they move to each other, the frequency received by the observation point are above the waves source. When they move to each other, the frequency received by the observation point are below the waves source. The greater the relative motion of the speed is, the more different between the receive frequency and waves source.

Doppler frequency shift refers to the frequency offset between the carrier of the emission radio frequency and the reflection from the moving target echo . Doppler frequency shift is proportional to the relative speed deviation:

$$f_d = 2V / \lambda \qquad (1)$$

f_d ——Doppler frequency shift(Hz) ;
λ ——wave length(m) ;
V ——Relative speed(m/s);

2.2 The Echo Signal Model

We have mentioned that the wind shear echo signal is composed of two parts, the weather rain echo signal and noise. We must build two signal model of signal model, the rain weather echo signal model and ground clutter model. Specifically, both ground clutter and wind shear echo signal are based on the doppler effect. For the echo signal of each gate distance , we can be calculated them by the following two formulas, n presents the NTH pulse, T_s is on behalf of the pulse interval that is the echo signal with phase and orthogonal air volume . I, Q, are respectively computed by

$$I(nT_s) = \sum_{i=1}^{N} A_i \cos[\bar{\phi}_i + \beta(V_i - V_a)nT_s + \Delta\bar{\phi}] + \bar{n}(nT_s) \qquad (2)$$

$$Q(nT_s) = \sum_{i=1}^{N} A_i \sin[\bar{\phi}_i + \beta(V_i - V_a)nT_s + \Delta\bar{\phi}] + \bar{n}(nT_s) \qquad (3)$$

In the pulse of doppler radar, the problems are the fuzzy between distance and speed.so The largest no ambiguous doppler velocity is set to $V_{\max} = PRF(\frac{c}{4f_s}) = 30.032258$ m/s. We build the wind field of antenna scanning radial maximum speed to be less than 20 m/s, which is no more than the biggest fuzzy speed. So the wind field model can be directly established, and the characteristics of echo signal factor can be analyzed through frequency domain .

Assuming radar transmitter power is P_t , antenna gain is G , target slant distance is R , radar working wavelength is λ , and target scattering rate is σ . The basic radar equation is:

$$P_r = \frac{P_t G^2 \lambda^2 \sigma}{(4\pi)^3 R^4} \qquad (4)$$

In the term of the weather radar, when the target is point target, we set a goal for effective scattering area to be σ', then

$$P_r = \frac{P_t G^2 \lambda^2 \sigma'}{(4\pi)^3 R^4} = \frac{P_t G^2 \lambda^2 v\sigma}{(4\pi)^3 R^4} \quad (5)$$

And V is the volume of the beam

$$\sigma = \frac{\pi^5}{\lambda^4} |K|^2 D^6 \quad (6)$$

D is the diameter of the ball

$|K|^2$ is the dielectric constant of scattering particles, we often take that of ice and water to be 0.20, 0.93.

$Z = \sum D^6$, refers to the reflectivity

Therefore, given the reflectivity factor, we can calculate σ to get the echo signal.

(1) Wind shear rain echo signal

The wind shear rain echo signal is mainly the change of wind speed in wind field and the echo signal of scattering particles on transmitting scattering. The echo signal simulation is mainly rain phase and amplitude changes, which is decided by the doppler frequency shift, the wind field reflectance, reflection unit, and the antenna gain radar cross-section. Signal amplitude A_i is determined by the radar equation and reflectivity:

$$A_i = \sqrt{\text{CP*ETA *XLOSS*CVOL}}\text{*GAIN} \quad (7)$$

$\text{CP}=\dfrac{\text{P}_\text{t} * \lambda^2}{(4\text{*pi})^3 \text{*R}^4\text{* RCVR\_LOSS}}$ is the radar equation of constant, P_t is radar transmitted power, λ is the wavelength, RCVR_LOSS is the receiver signal loss, XLOSS is the two size attenuation factor, reflectivity, ETA stands for wind shear wind field, CVOL means the scattering infinitesimal volume, GAIN is the antenna, and R is the the distance from scattering unit to the antenna.

Signal phase is mainly decided by the doppler frequency shift. The doppler frequency shift is composed of two parts that is respectively V_i and V_a. They are produced by the wind shear scattering and plane along the radial velocity component ω_i and ω_a, which is $\omega = \omega_i + \omega_a = \beta(V_i - V_a) = \frac{2\pi}{\lambda}(V_i - V_a)$. $\beta = \frac{2\pi}{\lambda}$ is constant, $\overline{\phi_i}$ is the random phase scatterer, $\Delta\overline{\phi}$ is the phase error for launch, and $\overline{n}(nT_s)$ is the receiver noise. So the total rain echo signal phase is:

$$\psi = \overline{\phi_i} + \beta(V_i - V_a) + \Delta\overline{\phi} \quad (8)$$

(2) The ground clutter

Low-level wind shear detection radar working in aircraft takeoff and landing stage of the aircraft from the ground level is very low, generally less than 300 m, we established the wind field model is the range of 0-300m height. The low height leads to the ground clutter signal very strong. So the only way to make radar suppress the airport environment clutter is to simulate clutter environment .

First establish a geographic coordinate system of carrier aircraft. The following is a geographic coordinate system of carrier aircraft. The aircraft and the radar clutter geometric position as shown in the figure below:

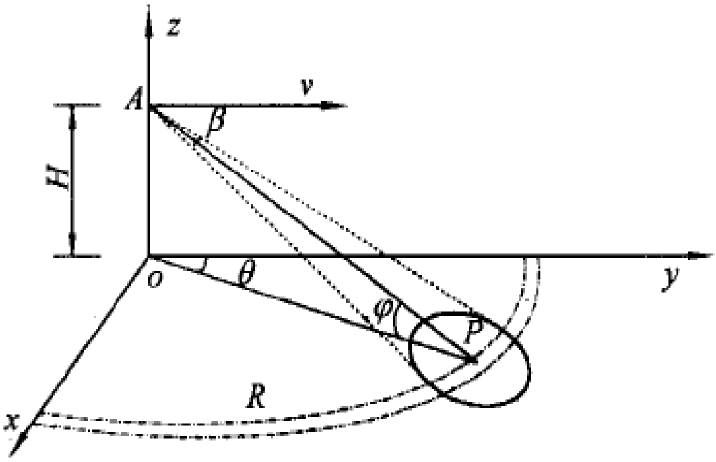

Figure 1. The Carrier Aircraft Geographic Coordinate System

For the fixed ideal movement of the PD radar, its the ground clutter spectrum density function in transmitting frequency is on a single line (after distance wave gate and narrow-band filtering). Taking the visual features of airborne PD radar as an example, in the case of PD radar in a sport, If the relative motion speed of the radar to the ground is V, the clutter spectrum is broadening by the relative motion speed. The scope of the doppler spectrum in doppler frequency of radar velocity are along the positive side and negative side. With apparent under the conditions of the airborne PD radar, for its part, the ground clutter can be roughly divides the mainly clutter, side lobe clutter and highly clutter three categories, as shown in figure 2:

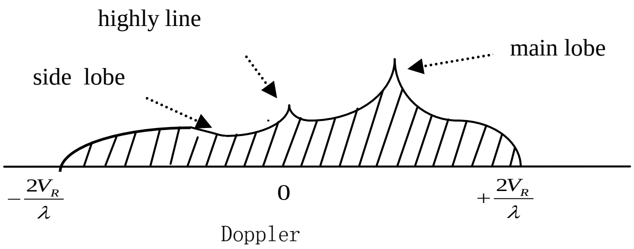

Figure 2. The Ground Clutter Spectrum Diagram

Because the influence of shear echo signal for the side lobe and height line clutter is very small compared the main lobe clutter, we focus our research on the main lobe clutter. The ground clutter signal amplitude A_i is decided by radar equation and reflection unit department reports radar cross-section SIGO:

$$A_i = \sqrt{\mathrm{SIGO*AREAC*CP}}*\mathrm{GAIN} \qquad (9)$$

$\mathrm{CP}=\dfrac{\mathrm{P_t}*\lambda^2}{(4*\mathrm{pi})^3*\mathrm{R}^4*\ \mathrm{RCVR\_LOSS}}$ is the radar equation of constant, AREAC is the ground scattering surface micro product, GAIN is the antenna gain, SIGO reports the unit radar cross-sectional area of the reflection unit .

$$SIGO = A*(\theta + C)^B \exp[\frac{-D}{1+K}] \qquad (10)$$

A, B, C, D is determined by the reflection type on the ground. The specific parameters are seen in the table below:

Table 1. The Reflecting the Ground Type Corresponding to a Constant Value

Constant	Field	Lawn	Grass	Tree	City	Wet snow field	Dry snow fiedl
A	0.25	0.023	0.006	0.002	2.0	0.025	0.195
B	0.83	1.5	1.5	0.64	1.8	1.7	1.7
C	0.0013	0.012	0.012	0.002	0.015	0.0016	0.0016
D	2.3	0.0	0.0	0.0	0.0	0.0	0.0

In the signal simulation D = 0. θ is the antenna scanning pitching Angle, $K = \frac{0.1*SD}{\lambda}$, and SD is the standard deviation of the reflection surface. we take it to be 0.5. The ground clutter signal phase is mainly determined by the plane radial velocity of the airflow, and the scattering body along the radial velocity component V_i = 0.

$$\psi = \overline{\phi_i} - \beta V_a + \Delta\overline{\phi} \qquad (11)$$

For the convenience of filtering clutter , we usually remove the aircraft's speed. So it is finally concluded that the clutter signal spectrum are basic situated near the zero frequency, and we design a high-pass filter to remove noise signals. After the ground speed is removed from the echo signal, only the wind velocity component of wind shear remains. Then we get rid of speed, filter out noise, and directly obtain the specific micro critical wind field position, the micro critical wind speed, and the micro flow characteristic parameters from the signal.

3. Simulation and Results

We have studied that the simulation principle of echo signal is doppler frequency shift, so we get the phase of the echo signal through frequency shift. The amplitude is mainly composed of the radar equation, the path attenuation and antenna gain decision. Our scanning antenna azimuth range is - 23 ~ 23 deg, pitching Angle scanning range of 0 ~ 4 deg, we azimuth scanning from the azimuth Angle of the left, then the initial azimuth Angle to - 23 deg, azimuth scanning range was divided into 46 scan lines, each line is 1 deg, and then to divide the line according to the distance, distance is divided into fifty doors, each 150 m from the door, starting from the door of 1 km, distance to the door, as a small unit for elementary integral operation, accumulative calculation of the sum of 128 pulse echo signal, finally concluded that the distance between gate of echo signal. After scanning the 46 scan lines, such as antenna azimuth direction of the scanning of the adjustment, the adjustment for the reverse, antenna pitching Angle adjustment, also revised down 2 deg, 46 aircraft position according to scan the scan lines used to adjust the time and speed of the plane. Initial elevation Angle of the antenna is 0 deg, the pitching Angle adjusted to 6 deg, less than 4 deg, carries on the pitching Angle to zero, to prevent the main lobe of the antenna is too low, cause the echo signal of mixed with ground clutter signal.

The simulation results shows that when we get wind speed is 0 and the reflectivity is 0 DBZ too, we can remove the ground speed of the aircraft. The aircraft along the antenna beam radial velocity is 0, doppler frequency shift is 0, and the echo signal basic situated near the zero frequency. Because of low reflectivity and the low signal amplitude, there is no wind shear warning signal. The rain echo signal are as follows in figure 3, figure 4:

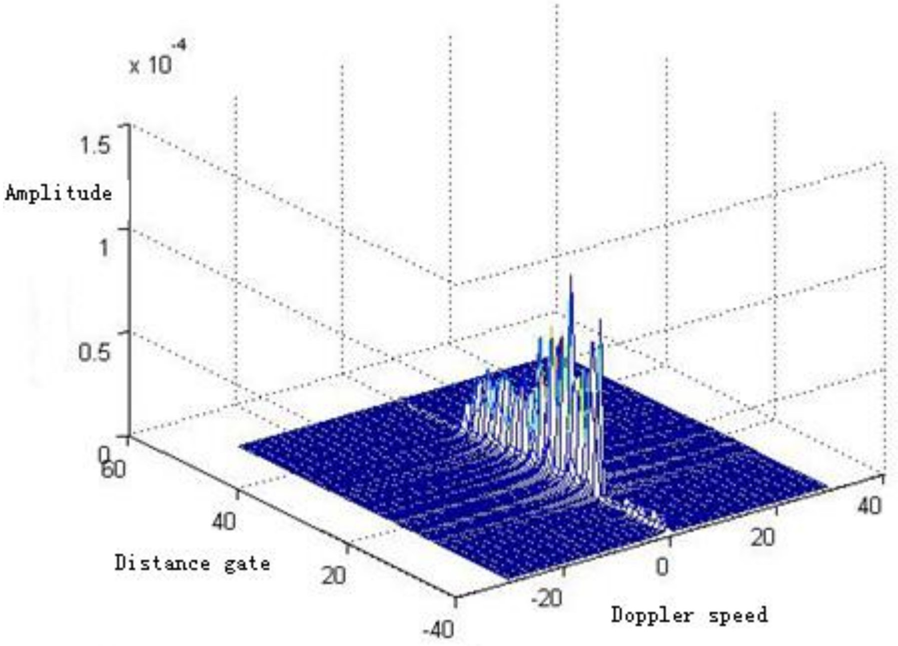

Figure 3. Rain Echo Signal Amplitude Spectrum (Reflectivity is 0, Wind Speed is 0)

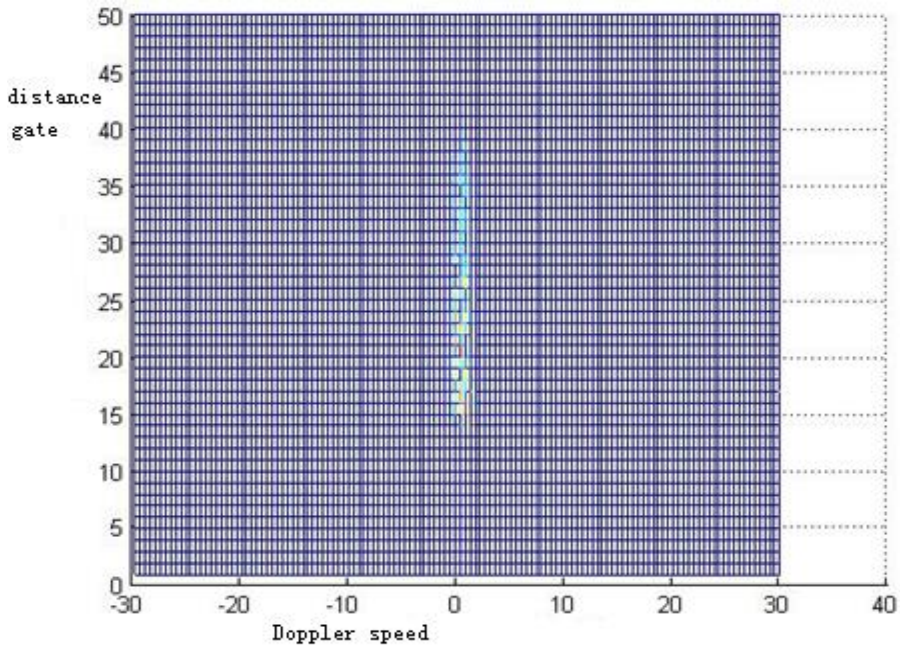

Figure 4. Rain Echo Signal Amplitude Spectrum Vertical View (Reflectivity is 0, Wind Speed is 0)

When reflectivity is 30 DBZ, figure 5and figure 6 are the first line of the echo signal amplitude spectrum. The antenna beam sweep is just at the edge of strike suddenly and violently wind are under the micro field. The wind speed are almost perpendicular to the radial, and the radial velocity component is zero. We remove the ground speed of the aircraft, as the aircraft along the radial velocity of antenna beam, it almost does not produce doppler frequency shift, nor speed. The doppler speed is almost to zero.

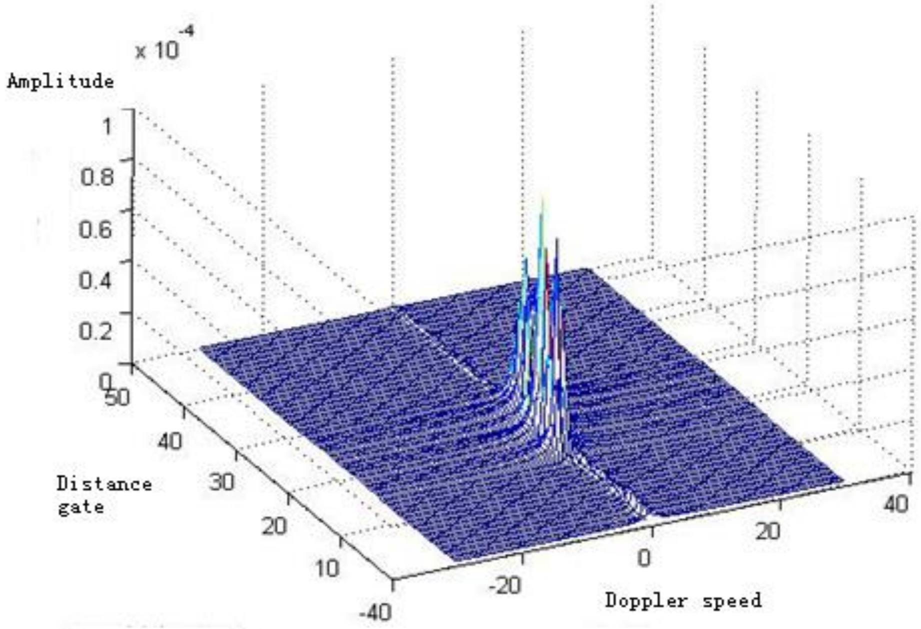

Figure 5. The Rain Echo Signal Amplitude Spectrum (The First Scan Line)

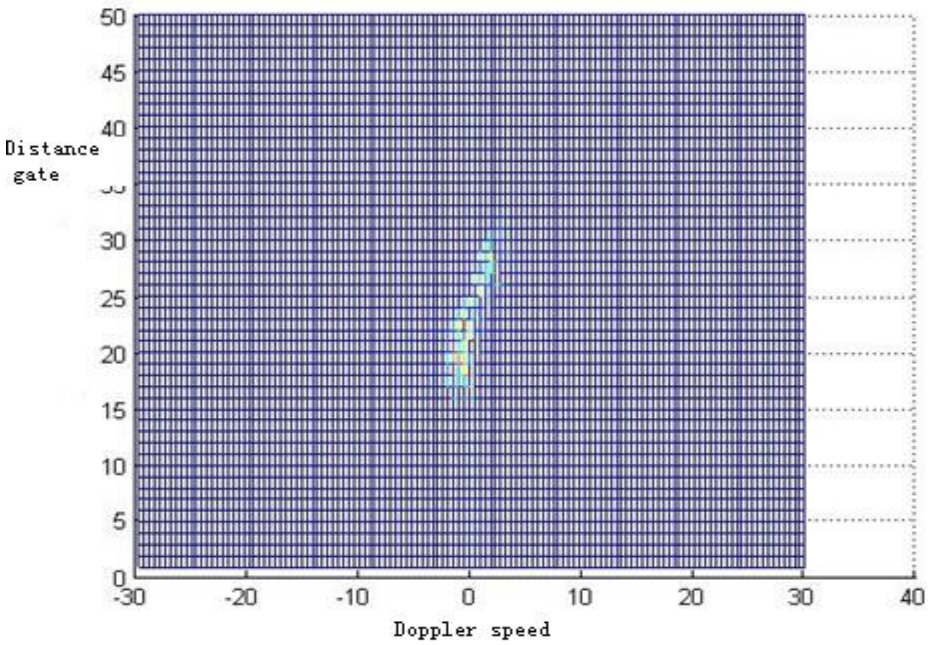

Figure 6. The Rain Echo Signal Amplitude Spectrum Vertical View (The First Scan Line)

The following figure shows the 22nd scan lines in the spectrum of echo signal changing with distance door. The 22nd azimuth scanning beam mainly point to the center, the center of the beam center point is about micro critical wind field, the figure 7, figure 8 are the rain echo spectrum diagram.

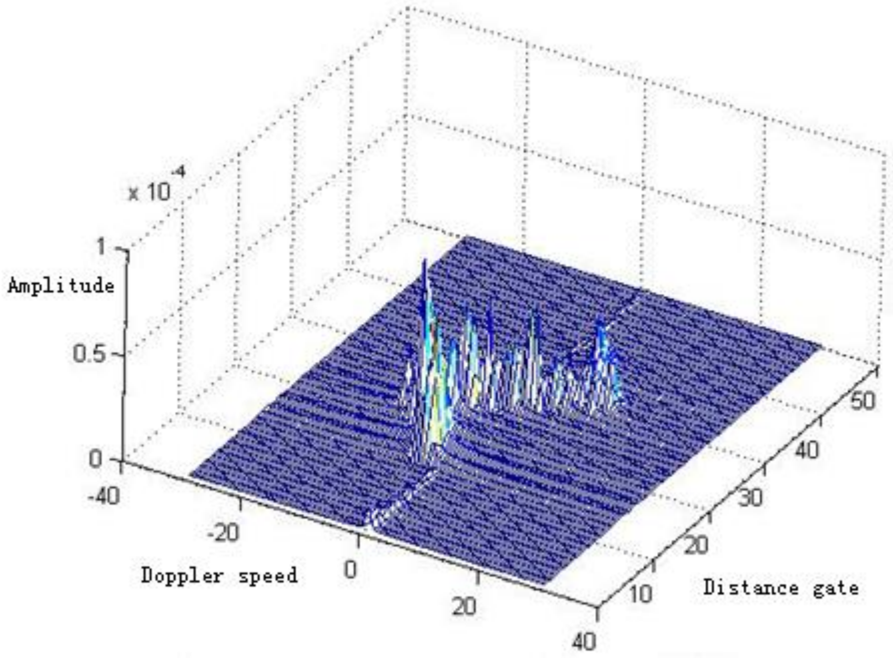

Figure 7. The Rain Echo Signal Amplitude Spectrum (The22th Scan Line)

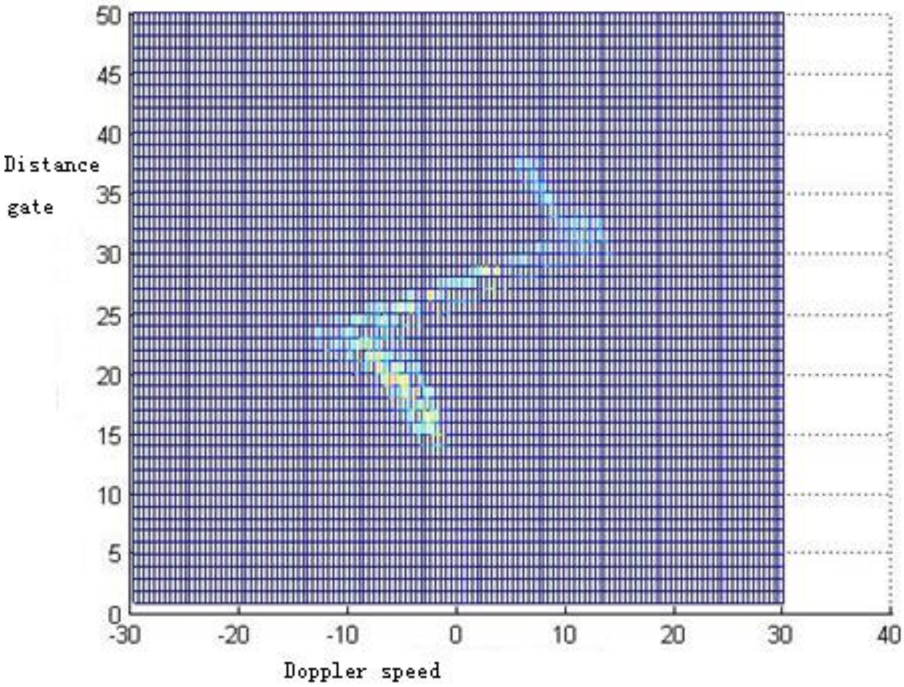

Figure 8. The Rain Echo Signal Amplitude Spectrum Vertical View (The 22th Scan Line)

Figure 9 is ground clutter echo signal spectrum, we can see the ground clutter echo signal amplitude is relatively high, is much better than the rain echo signal, figure 10 is the total signal spectrum diagram, see from figure 10, the ground clutter signal is very strong, basically have overwhelmed the rain echo signal.

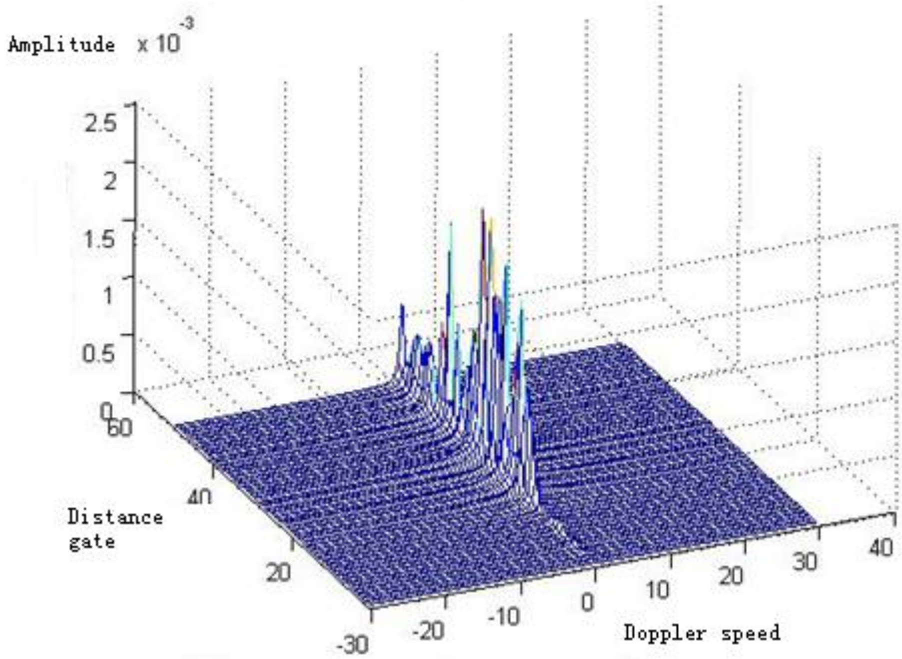

Figure 9. The Ground Clutter Velocity Spectra (The 22th Scan Line)

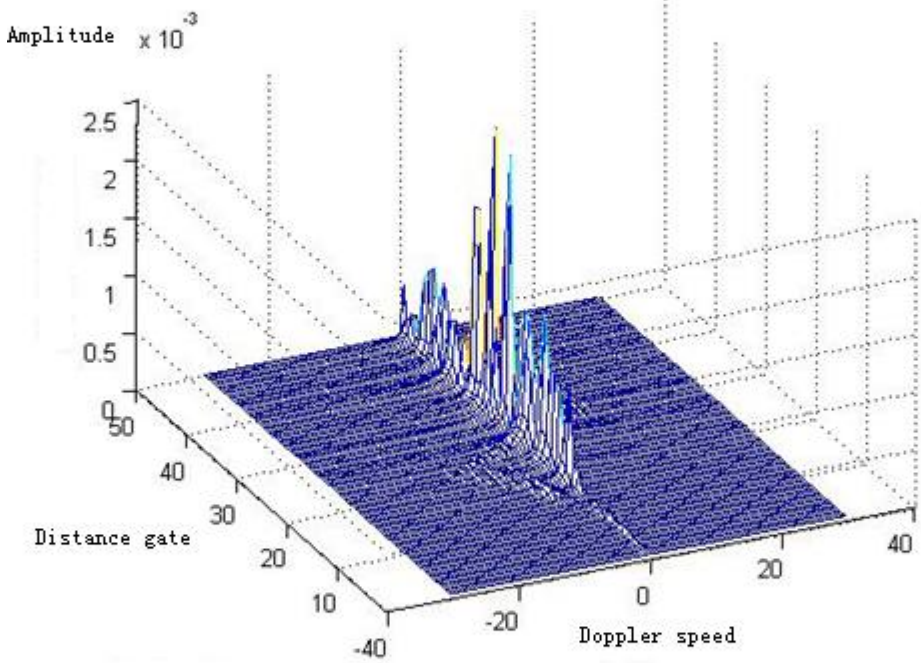

Figure 10. The Total Echo Signal Amplitude Spectrum (The 22th Scan Line)

4. Conclusion

The echo signal frequency domain modeling has been introduced in this paper. It is mainly divided into two parts: the wind shear rain echo signal and noise. It introduces the basic principle of modeling, simulation modeling process, the modeling simulation, and finally discusses the results of simulation analysis. Wind shear echo modeling is the basic principle of doppler frequency shift, the wind speed and flight speed difference of doppler frequency shift. Through frequency shift of the planes we can get the distribution size of wind field wind speed ahead. The modeling and simulation are including antenna simulation, coordinate transformation and echo signal simulation model.

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References

[1] J. Zhao, X. F. Liao, S. Y. Wang and C. K. Tse, IEEE Signal Processing Letters, vol. 7, no. 22, **(2015)**.
[2] S. K. Singh and A. K. Goswami, International Journal of Electrical Power & Energy Systems, vol. 67, **(2015)**.
[3] Y. L. Zhou, Q. Z. Zhang and Y. X. Yin, “Mechanical Systems and Signal Processing, vol. 56, **(2015)**.
[4] M. Sayin, Y. Yilmaz and A. Demir, Signal Processing, vol. 109, **(2015)**.
[5] E. G. Baxa, “New signal processing developments in the detection of low-altitude wind shear with airborne Doppler rada”, Proceeding of IEEE National Radar Conference, **(1993)**; Boston.
[6] C. L. Britt and C. W. Kelly, “User Guide for an Airborne Wind Shear Doppler Radar Simulation (AWDRS. Hampton: NASA Langley Research Center), **(1990)**.
[7] B. Widrow, J. Mccool and M. Ball, Proceedings of the IEEE, **(1975)**.
[8] E. Baa, Y. C. and G. Lai, “New signal processing developments in the detection of low-altitude windshear with airborne Doppler radar”, Record of the IEEE National Radar Conference, **(1993)**.
[9] M. W. Kunkel，"Spectrum Modal Analysis for the Detection of Low-Altitude Windshear with Airborne Doppler Radar", **(1992)**; NASA，USA.

Author

Meng JIA

