Research on X-Band Doppler Weather Radar with Dual-Linear Polarization Capability

Zhang Ziliang[1 3] Zheng Guoguang[2] Liu Xinan[1]

[1]Nanjing Research Institute of Electronics Technology，Nanjing，(China)

[2]China Meteorological Administration，Beijing，(China)

[3]Nanjing University of Information Science & Technology， Nanjing，(China)

【Abstract】 In this paper, a X-band Doppler weather radar system with dual-linear polarization capability is described and the key technological problems are discussed. The experimental radar is used to observe the precipitation and intensity distribution. The precipitation, hail, snow signature are recorded and analyzed. Test results show that this system has a compact structure and good performance.

【Key words】 Doppler weather radar, Dual-linear polarization

1 Introduction

Since Seliga et al (1976) presented the assumption of dual-linear polarization radar, the early dual-linear polarization radars were developed on the basis of conventional pulse radar. With the development of digital technology, the Doppler weather radar is becoming mature to mature, and shows more notable technical advantages. The Doppler radar features with excellent performance and complete functions, which can not only measure the location and strength of precipitation, but also provide the radial component of the wind vector and flow course of internal air stream within the precipitation. Much research work conducted by radar and meteorological experts shows that, the Doppler radar with dual-linear polarization function will have higher rain-measuring accuracy and obtain many microphysical information related to precipitation particle, such as its size、shape and phase, etc.. This kind of radar can further improve the monitoring and forecasting ability against disaster weather and is significant for raising the weather forecasting servicing level, thus it is becoming the important tool of new generation for meteorological sounding. In recent years, some countries and areas, such as the United States, West European, Japan, have designed various of experimental system. Combined with Doppler and dual-linear polarization technology, the synthetic researches on rain-dropping, cloud, frog, hail, etc. are becoming the development trend for some important meteorological research departments. With the development of radar and meteorological technologies, we developed an experimental Doppler dual-linear polarization radar. After a period of observation, some parameters related to dual-linear polarization were obtained, which have been used for research and analysis. The research results show that this experimental system features with excellent performance.

2 Dual-linear polarimetric Doppler radar system and information processing

2.1 Information processing of dual-linear polarization

The dual-linear polarization radar can be called a multi-parameter measuring system. The radar transmits the horizontal polarization and vertical polarization pulses alternatively or simultaneously, and receives the echoes, reflectivity factor Z_{HH} and Z_{HV} (e.g., horizontal, H, and vertical, V) by horizontal transmitting and the echoes, reflectivity factor Z_{VV} and Z_{VH} by vertical transmitting, thus it can measure multiple polarization parameters of hydrometeor. The Doppler radar can also evaluate the phase difference $\Phi_{DP}=\Phi_{H}-\Phi_{V}$ of horizontal and vertical polarized echoes. Besides the echo strength $Z_{(dBZ)}$ at horizontal polarization, the function of dual-linear polarization can measure differential reflectivity factor Z_{dr}, specific differential phase shift K_{dp}, linear depolarization ratio L_{drH} and L_{drV}, copolarization correlation coefficient ρ_{HV}, etc..

Defined as the difference between the horizontal echo strength and the vertical echo strength, the differential reflectivity factor is sensitive to the average shape of water particle. The flattening of flat elliptical shape of raindrop is dependent on the size of raindrop, and Z_{DR} is an evaluation for average size of raindrop. Thus , it is much more accurate to evaluate the rainfall by combining Z and Z_{DR} than using the value of Z only. When the ice has a shape like needle or plate and are dropping with horizontal orientation, Z_{DR} will have a larger value. For tumbling hail during dropping course, its Z_{DR} approaches zero. As the most important parameter for dual-linear polarization system, the differential reflectivity factor is express by dB: $Z_{dr}=Z_{HH}-Z_{VV}$. It shows the phase state of hydrometeor in the air. For rain, snow, ice, hail, etc. with different phase state, Z_{dr} is within -1～+4dB.

The differential propagation phase shift is the difference of propagation phase shift between horizontal polarization wave and vertical polarization wave while they pass in different media with different velocities. When the radar wave pass through a group of raindrop with flat elliptical shape, the velocity of the horizontally polarized wave is slowed relative to that of vertical wave, thus the phase difference for Φ_{DP} between two polarization waves rises with the range. K_{DP} is closely related to rain rate than radar reflectivity z. its processing algorithm is based on Doppler signal processing.

$$K_{dp} = (\Phi_{HH}-\Phi_{VV})/\Delta r$$

or

$$K_{DP} = \frac{180\lambda}{\pi}\int_0^{D_{Max}} \left(f_H - f_V\right) N(D) dD$$

where f_H and f_V are forward scatter amplitudes at H and V polarization, λ is the wavelength , D is the drop diameter , N(D) is number density .

its value is within -1～+10°/Km.

Linear depolarization ratio LdrH and LdrV are good detectors for grains of wet ice. In thunderstorms , LDR can determine the existence area of wet hailstones. In stratocumulus system, LDR can identify melted snow. Linear depolarization ratio is the ratio of two polarized components from receiving signal during horizontal (or vertical) launch:

$$LdrH = Z_{HV-} Z_{HH}$$

$$LdrV = Z_{VH-} Z_{VV}$$

Its value should be –34~+30 dB;

Data processing of above-mentioned multiple parameters presents a complicated task before the signal processing system and various algorithms are included. For example, methods such as direct estimation of value for correlation functions and Mueller (1984) can be used during computation for differential propagation phase shift K_{dp}, deviation of estimated value from various methods is greatly different. Different processing modes and algorithms for dual line polarized signal processing are of great effect to the processing results. It is very important to select rational and proper mode and algorithm.

Computation precision of factor Z_{dr} is determined by the number of samples sampled independently from signal samples. Radar system must extract enough echo sequence samples and is of great flexibility so as to process various modes and algorithms, all above present strict requirements for the radar operation mode and signal processing. At the same time, errors resulting from the rainfall attenuation in differential reflectivity factor cannot be negligible, and attenuation correction must be done according to radial range. (Liu Liping et al.1992)

Complexity of dual line polarized signal processing is also shown in inter-influence exerted in Doppler processing. Although propagation phase shift difference can be gained by Doppler signal processing, computation of correlation coefficient ρ_{HV} for common polarization is effected by Doppler velocity signal.

2.2 Introduction to the System

Doppler dual linear polarization meteorological radar system is of full coherent PD type and features high-stability LO amplifier transmitter, low noise big dynamic digital receiver, low side lobe antenna, digital signal processing and real time picture terminal. The system can measure the intensity Z of meteorological echo and its characteristics of regional distribution in ground clutter environments, the system can also measure the radial velocity V of the scatter and velocity spectrum width W. Appliance of dual linear polarization technology results in that the radar system features powerful performance, gets more information about the shape and phase state of precipitation cloud and extracts such dual linear polarization parameters as Z_{DR}、 K_{DP}.

A perfect Doppler dual linear polarization system includes: the transmitter, dual channel receiver, dual channel signal processing system, data processing system, antenna feed line and servo system plus terminal display and control system.

Block diagram of the system is shown in Fig.1.

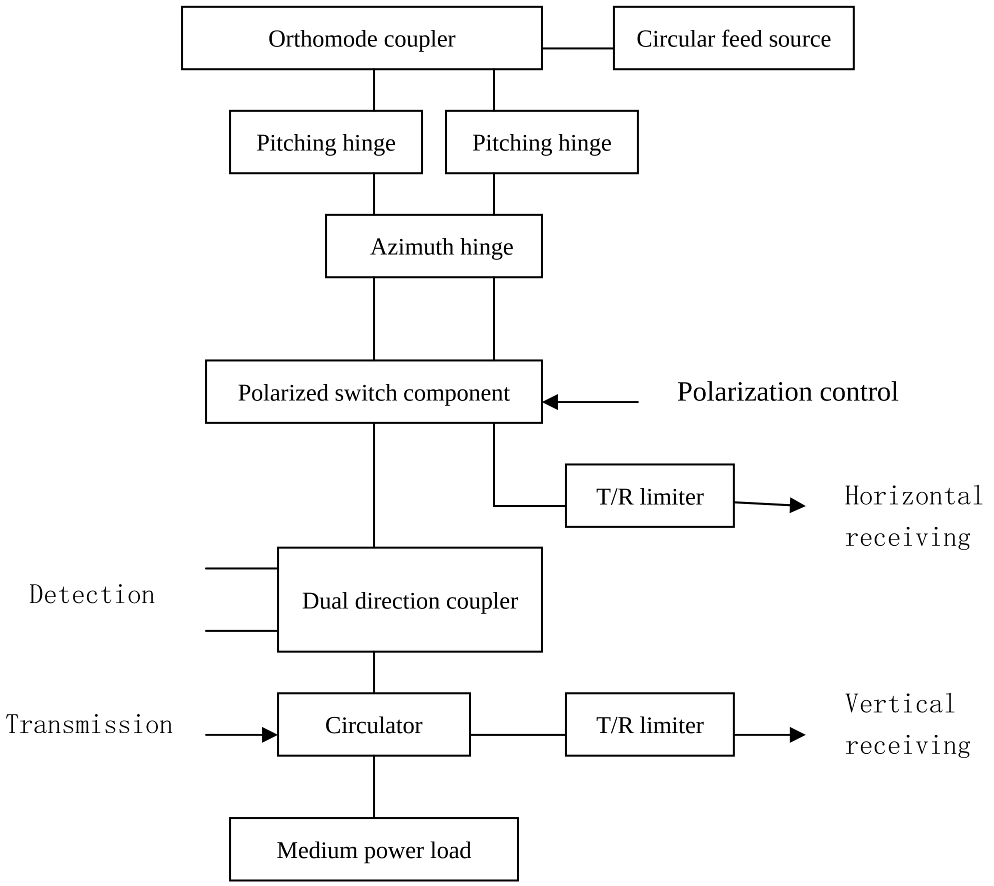

Fig.1 Block diagram of dual channel system

The above system has the following features:

1) The plan of horizontal/vertical time-shared transmit and dual channel synchronous receive is used to be profitable to extract linear depolarization ratio (LdrH/V) signal. The system has the coherent performance of canceling bi-stroke (second-trip echoes) distance ambiguity.

2) High speed (Microsecond class) and highly isolated polarization

switch is used to realize pulse-to-pulse polarization conversion, and to meet the demand of time relation for horizontal transmit and vertical transmit. High isolation will improve the signal quality.

3 Key technology of dual linear polarization

The key technology of dual linear polarization is to use high performance microwave ferrite material, compound wave-guide loading technique and high power resistant excitation control technology, so to realize the polarization switch of high speed, high power polarization conversion. The isolation of the switch is more than 30dB, the switch time is less than 5μs, power resistance is higher than 100kW. In addition, since the statistical quantity of the differential value of dual linear polarization parameters Zdr, Kdp and etc. measured for the system are all small values, so the standard of the measuring system is very high. So, the test accuracy of the radar system is much higher than that of the common system. For example, differential reflectivity factor Zdr, accuracy of linear de-polarization ratio Ldr is 0.2dB, differential propagation phase shift accuracy is 0.2°, these are very strict requirements to the system. Any small error in any part of the radar system will have very severe effect on the test result. Apart from the special requirements of the Doppler radar, accuracy of any part of the radar will become the core of the key technology of design and application of the dual linear polarization system. Besides, the following aspects are also very important:

1) Stability of the signal system. It includes the stable transmission power, stable receiving channel, accuracy of signal processing mode and calculation, strict control of the signal quality (to reduce processing error), etc.;

2) Stability of antenna feed system. It includes stability of the loss of the antenna feed system under different time and different temperature;

3) Low side-lobe antenna requirement. Weather radar uses negative feed parabolic antenna, the veil caused by the complex dual linear polarization feed will have effect on antenna performance. The synthesis energy of the antenna side lobe will all become the source of the test error. It is necessary for the antenna has the side lobe low as –27dB.

4) The operation environment of the equipment should be strictly required, for example, power supply, grounding, electromagnetic environment, weather, etc.

4 Dual linear polarization experimental radar system

We have devised a one-channel dual linear polarization experimental system for several years on the basis of the strict system specifications and the polarization switch of high performance. Its main system specifications are shown in Table 1.

Table 1 technical performance of the test system

Frequency	9375 MHz
Antenna type	Positive feed paraboloid, 2.4 m
Scan range: azimuth elevation	360° 0--90°
Detection range	100,200,400 Km
Beam width First sidelobe	< 1° < -27 dB
Transmitter type	Klystron / solid state modulator
Power	> 60 kW
Pulse width/PRF range	1--4μs/500—1400Hz
Polarizations	Linear horizontal/vertical high-speed polarization switch
Noise factor of receiver	< 3 dB
Signal processing	FFT/PPP multi-mode
Data output	Z, V, W, Zdr, Kdp

During its operation, the system has obtained many clear measured pictures about the weather process and the recognizable results about the rainfall and the snow. The map of differential reflectivity factor Zdr obtained during a certain rainfall measurement is shown as Fig. 2. It is proved by analysis and research that the system has relatively good Doppler dual linear polarization performance.

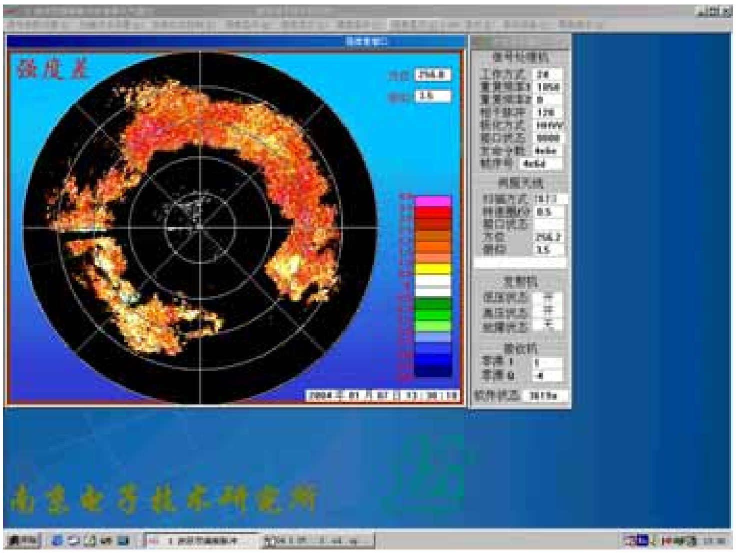

Figure 2　Map of differential reflectivity factor Zdr

References

1. Performance Requirements for Dual Linear Polarization Meteorological Radar (draft), Bureau of Meteorology of China
2. Zhang Ziliang, Dai Chengsong , NRIET restricted material ,Scheme of X Band Dual Linear Polarization Doppler Meteorological Radar.
3. Seliga T A,V N Bringi. Potential Use of Radar Differential Reflectivity Measurement at Orthogonal Polarizations for Measuring Precipitation. J A M, 1976,15: 69--76
4. Liu Niping, Ge Runsheng, Zhang Peiyuan，　The study of the Method and the Accuracy to Measure Remotely the Strength of the Rainfall and Liquid Water Content of Dual Linear Polarization Doppler Meteorological Radar，Atmospheric science，2002，26（5）:709—720

5．Liu Niping, Xu Baoxiang， The Analog Computation and Discussion about the Problem of Attenuation Correction in the Rain Area of the Dual Linear Polarization Radar, Plateau Meteorology，1992，11（3)：235--240

6. Mueller,E.A., 1984: Calculation procedure for differential propagation phase shift. Preprints. 22d conf. On Radar Meteorology, Zurich, Switzerland, Amer. Soc., 397-399