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Developing X-band Magnetron Doppler Radar for Weather Modification

Zhendong Yao(1), Yong She(1), Jian Li(1), Yuming Du(1), Shuo Wang(1), and V. Chandrasekar(2)
(1) Key Laboratory of Atmospheric Sounding, Chengdu University of Information Technology, Chengdu, China, 610023, http://www.cuit.edu.cn
(2) Colorado State University, Co., USA

Abstract

Magnetron transmitter, coherent-on-receive Doppler radar can get cost effective advantage. Detection abilities of reflectivity and mean radial velocity make it very suitable for heavy precipitation short-time nowcasting and weather modification operation command. WXR-MD-2010 radars, which we developed by this way, have been successfully used for these purpose and airports aviation weather services. These radars operate at x-band, with options of transmitting power of 10 or 25 kW in 1μs, and receiver sensitivity is better than -105 dBm. FPGA based digital receiver and digital signal processor, can rise more than 20dB of SNR improvement, expand receiver dynamic range up to 90dB, achieve image frequency rejection ratio better than 80dB (amplitude and phase are good equilibrium). In the 50km observation range, reflectivity measurement accuracy is within 1dB, and mean radial velocity measurement accuracy is within 1m/s.

1. Introduction

In past decades people try to do some things about weather modification, especially hail suppression and precipitation enhancement. Stanley A. et al. reported their research about hail suppression technology in 1976 and 1977 [1, 2]. They gave some models of hail detection, such as relationship of hail and reflectivity aloft and many experiments.

Evaluation of a hail suppression project was done later, such as the work by Jean Dessens, with 8 years statistic, the more heavily seeded hailfalls decrease by 42% [3].

Another hand, rain enhancement is not only achievable by making clouds to produce more precipitation. It is also possible to recycle the water more often and to add full or partial cycles of rain [4].

In generally, hail suppression is efficiency. WMO published a document on weather Modification in 2010, shown that extensively practiced glaciogenic seeding technologies have been used operationally in many parts of the world to reduce hail damage [5]. Dual-polarization Doppler weather radar is good facility for hailstorm detection and hail suppression. The currently research by G. Vulpiani et al., using polari-parametric to solve attenuation, can provide good rain–hail precipitation mixture identifying [6].

Weather modification is necessary for good agricultural production in many provinces in china.

And these works must be done with weather system data, which more efficiency is from real-time radar observation. Because weather modification office is funded by local county government, low cost and stability of radar is very important. So, it’s necessary to develop cheap magnetron radar in china.

Precipitation enhancement in winter and hail suppression in summer, these operation instructions are set by radar observation.

Three kinds of weather radar, model of XDR, XDPR and WXR-MD-2010, had been built for weather modifications in the past twenty five years.

2. Digitalization rebuilt for old weather radar

In china, in 1970’s, the CMA operation weather radar was analog radar, model 711, X band, which was designed based on vacuum tube, and transmitter was consist of thyratron pulse modulator and magnetron.

By the 1990’s, almost all the X band, model 711 weather radars was replaced by C or S band new generations with bigger peak transmitting power. Then the model 711 weather radars were idle. But the operation weather radar net couldn’t cover vast agriculture areas.

Although the model 711 weather radars were fault but their pedestals and antennas and wave guides could work well. So we collected some of these radars, and maintain pedestals, antenna and feed-line systems. Design and building new transmitters and receivers, and digital signal processors, good performance radars were rebuilt combined with these all things. The kind of radar was installed in many difference weather modification offices and had played an important part in operation.

Later, new pedestal, antenna and feed-line system was designed built, new X band weather radar was developed. That is XDR (X band Digital weather Radar), as shown in figure 1.

The radar operation frequency is 9375 ± 30 MHz, Transmitting peak power is 90±5 kW, pulse duration is 1.0 us, antenna gain/beam width is 38dB/1.5°, observation range is 100 km.

Because of high performance price ratio, and easily operating and simplified maintaining, XDR radars, which only work in reflectivity observation, were employed by many weather modification offices.

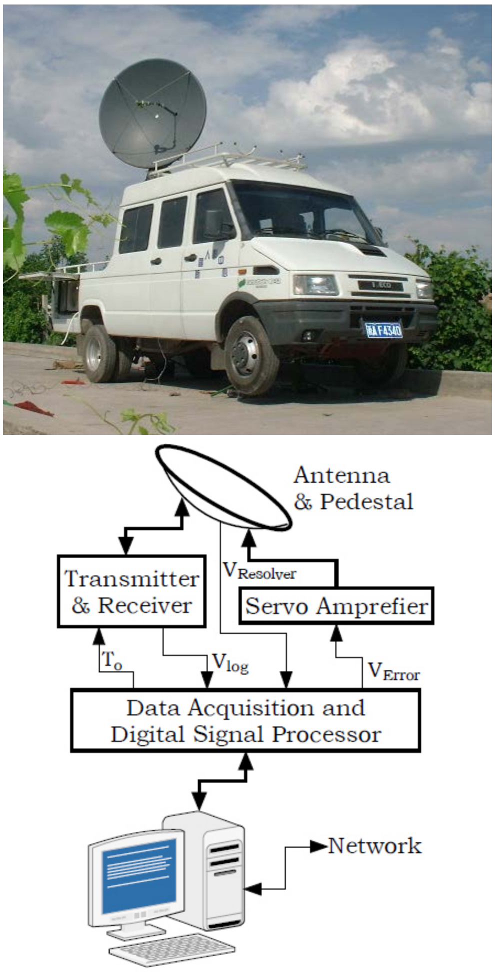

Figure 1. XDR radar system. Up is vehicle borne mobile radar, down is XDR block diagram.

3. Zdr detection weather radar experiment

In 1980's, all over the world, many researches and experiments were implemented for dual polarization radar and its observation. The abilities of identifying hail and classification of precipitation made polarization radar to be greatly concerned [7, 8, 9].

Xianqin Wang et al. had developed a kind of only-Zdr-detection simple dual-polarization weather radar for weather modification since 1994 [10, 11]. That is XDPR, which means X band Dual Polarization weather Radar.

The difference between XDR and XDPR are antenna and digital signal processor. Dual-polarization antenna used the same parabolic reflector similar XDR's, but was covered one layer of metal mesh. Its circular feed horn can through horizontal and vertical polarization wave. Polarization switch and controller generates these two waves for XDPR radar system. The detailed is shown in figure 2. The digital signal processor employed dual-DSP chips separates horizontal and vertical polarization echo, and accomplishes none coherent but correlated integration.

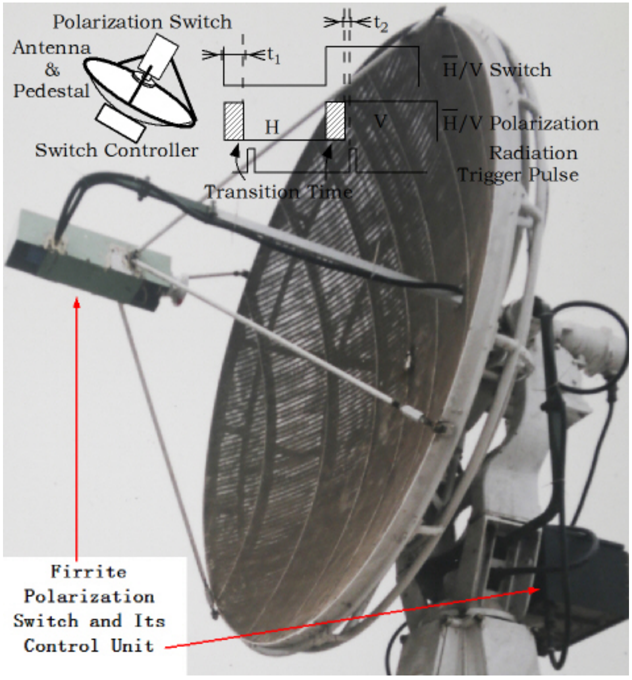

Figure 2. Dual-polarization Antenna with Polarization Switch and Controller for XDPR Radar System.

XDPR radar, which operates with alternate horizontal and vertical polarization transmitting and receiving, was experimented for several years and had gathered some data.

For some problems, such as the poor stability and isolation and too long response time of ferrite polarization switch, then the scheme of dual-polarization and the XDPR radar were given up.

4. Developing pseudo-coherent Doppler radar

In fact, although XDR's performance is not excellent, but its stability and reliability is good. So we develop a new type radar, WXR-MD-2010, using digital receiver and coherent-on-receive technologies, can hold reflectivity and radial velocity detections, and good performance.

4.1 Design and building

WXR-MD-2010 radar is designed by 6 parts, which are antenna and feed line system, servo control system, transmitter system, receiver system, digital signal processing system and computer terminal system, such as shown in figure 3.

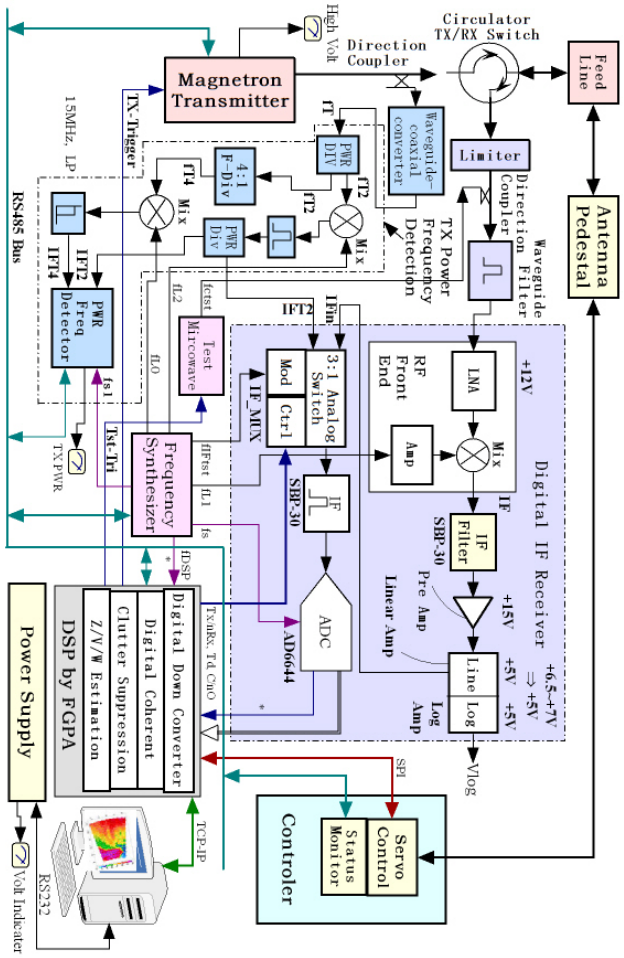

Figure 3. WXR-MD-10 Block Diagram (Note that the DDC-Digital Down Converter in Digital IF Receiver is put on DSP-Digital Signal Processor).

Antenna and feed line system includes a reflector with diameter of 2 m, horizontal feed horn, elevation and azimuth Rotary Joints, waveguides, circulator, waveguide limiter, direction couplers, waveguide-coaxial converter, coaxial cables, and waveguide filters, etc. All transmitting lose is smaller than 2 dB, and receiving 2 dB too. The gain of antenna is greater than 40 dB, beam width is smaller than 1.25°, and side lobe is smaller than -28 dB.

Servo control system is designed by TI DSP chip of TMS320F2407A, and accomplishes servo control and others of radar switch control such as transmitter turn on or off, radiation turn on or off, etc. Micro-resolver provides antenna angles signal, and is converted to binary codes by resolver to digital converter based on digital signal processing. These codes are used in servo control PID-fuzzy algorithm and antenna location indicator and digital signal processor. DC servo amplifier using PWM H bridge power circuits drives azimuth and elevation motors. Antenna position accuracy is smaller than 0.2° and speed of about 12～36°/s.

Transmitter system is designed by solid state high voltage high current pulse modulator, pulse transformer and magnetron. High voltage power supply is provided by DC-DC electric power circuits. High voltage large power switch is combined with IGBT series. Magnetron cooling can only by wind from axial fan. Radiation frequency is 9375±30 MHz, peak power can be selected 10 or 25 kW by changing magnetron and pulse cycle duration is 1 μs.

Receiver system is consisted of transmitting power and frequency detector, frequency synthesizer, digital IF receiver and test itself microwave signal generator. Transmitting frequency detector gives the magnetron frequency to frequency synthesizer, and this frequency plus an IF frequency as local oscillator frequency, is sent into mixer to convert the echo to IF signal. Then by filtering and amplifying, is digitalization with 100 MSPS sampling rate and becomes digital IF data. This signal is down converted into complex base band signal in digital signal processor. For checking by manual, a logarithm amplifier is used and can output a logarithm video. The sensitivity of receiver is set to -105 dBm.

Frequency synthesizer employs OCXO for frequency source, AD9520 time standard clocks which provides a multi-output clock distribution function with subpicosecond jitter performance, along with an on-chip PLL and VCO, SSN_2000A or SSN_2400A for local oscillator frequency, and MCU of MSP430F2132 for communication, optional and control.

Digital signal processing system is consisted of FPGA chip zynq-7000, and is programed as digital down converter (detailed in figure 4), digital coherent processor, ground clutter suppression filter, and Z/V/W estimation processor. With attached Gigabit Ethernet chip 88E1518, TCP-IP interface is accomplished here. Because using orthogonal sampling mode, the orthogonal processing of digital down converter front end can be designed as figure 4. The post decimation filter drop down the sample rate at 1 MSPS, and can get over 20 dB decimation gain. This gain plus ADC's SNR of 73 dB, radar system total dynamic range can arrive over 93 dB in theory and really over 90 dB. The words-length is 20 and 24 bits in digital signal processing, the unbalance of amplitude and phase is very small, and estimation of image frequency rejection ratio is better than 80dB.

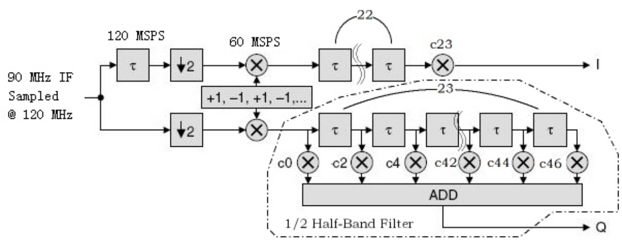

Figure 4. The orthogonal processing of DDC in FPGA.

Computer terminal system communicates with digital signal processor with Gigabit TCP-IP, and display and save the basic physical Z/V/W data. Total operation manuals and commands to radar hardware are finished here.

4.2 Observation and hail detection

The radar specifications can meet design values in the laboratory test. Since good performance on reflectivity and mean radial velocity, WXR-MD-2010 radars which based on magnetron transmitter and coherent-in-receiver, are replacing XDR radars.

The first update radar was installed in Weining county, Guizhou province, China. It is low latitude and high altitude mountain areas. During the commissioning period, thunderstorm had occurred. So the first batch of customer observation picture had been captured and combined in figure 5.

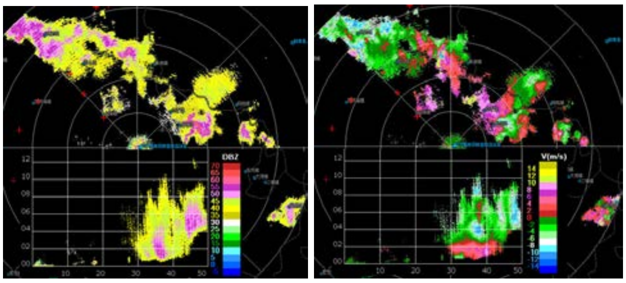

Figure 5. Observation on July 21, 2011. The range is 50 km, up-left, reflectivity PPI, up-right, radial velocity PPI, elevation: 6.2°, 19:53. Down-left, reflectivity RHI, down-right, radial velocity RHI, azimuth: 319.2°, 19:56.

The application software includes hail detection programs, which using reflectivity [12] and radial velocity [13] signature to find updraft or down draft or convergence etc.

5. Acknowledgements

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